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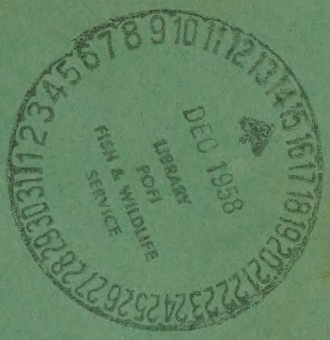

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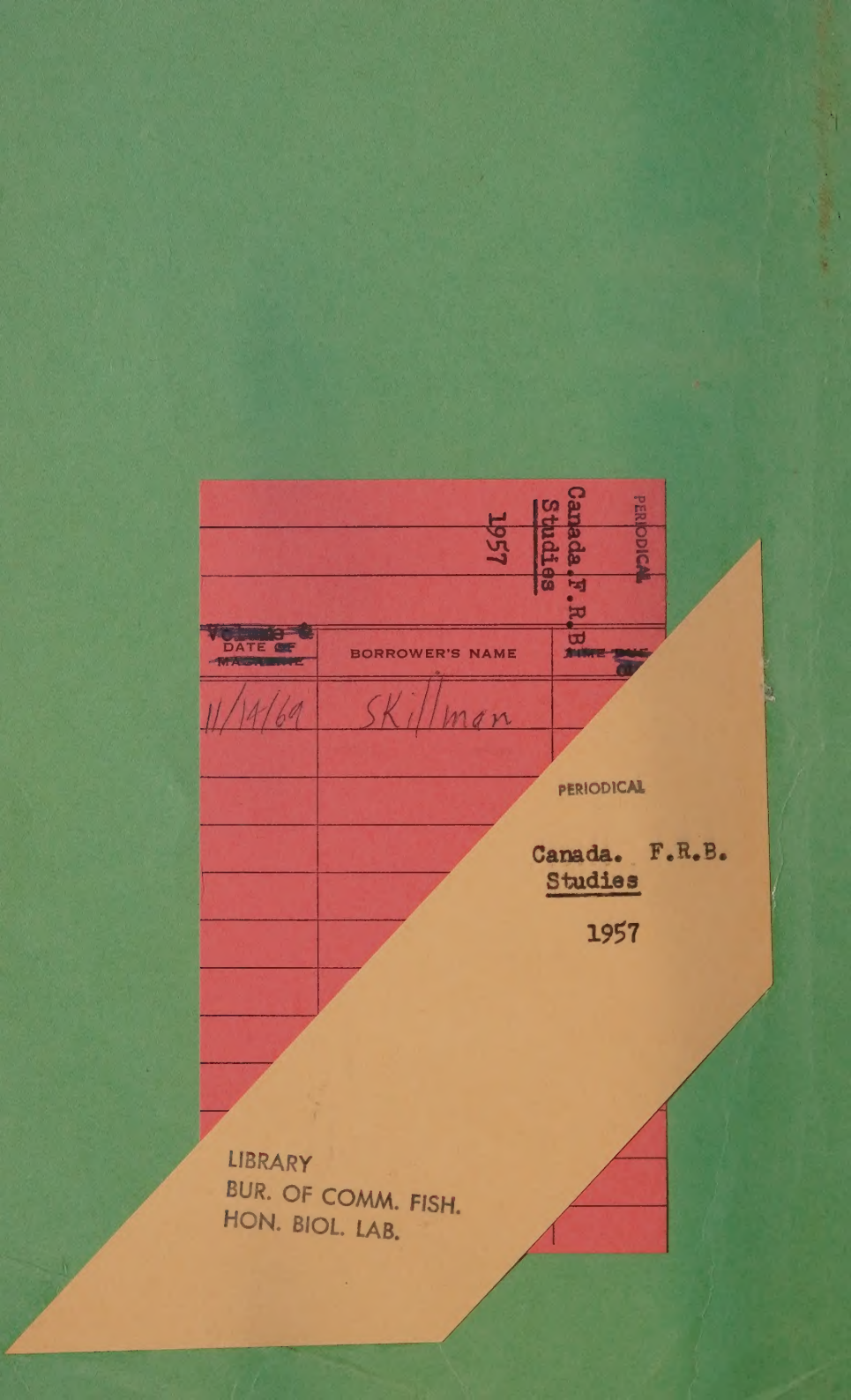
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MICROBIOLOGICAL FORMATION OF VITAMIN B_{12}

II. SYNTHESIS OF VITAMIN B_{12}-ACTIVE SUBSTANCES BY BACTERIA ISOLATED FROM CLAMS[1]

B. A. Southcott and H. L. A. Tarr

Abstract

Vitamin B_{12}[2] occurred in certain seaweeds and this vitamin and other cobalamins were demonstrated regularly in marine invertebrates. A *Bacillus* and a *Micrococcus* isolated from fresh clams were selected for detailed study on the basis of their pronounced ability to form cobalamins, and because they appeared to be typical of the bacterial flora of these invertebrates. The *Bacillus* formed vitamin B_{12} and other cobalamins, and this activity was stimulated by addition of Factor B and of certain purines or benziminazoles to the medium. With both organisms, 6-nitrobenziminazole proved particularly effective in stimulating formation of both vitamin B_{12} and of other cobalamins, and Factor B stimulated this activity. Formation of cobalamins was associated with a marked decrease in Factor B. The cobalamins were associated with the bacterial cells, and no cobalamin synthesis by washed cell suspensions in phosphate buffer was observed.

Introduction

In previous investigations carried out at this Station it was shown that clams (26) and other marine invertebrates (20) were usually good sources of vitamin B_{12}, and that this vitamin was readily formed by growth of certain streptomyces in fish press liquid (24). At that time it was known that vitamin B_{12} was a single compound (cyanocobalamin), and one in which the co-ordinatively bound cyano group was replaceable by other ions or molecules with formation of modifications such as hydroxo-, nitro-, and thiocyanatocobalamins (4, 19). Subsequent work, based largely on chromatographic and electrophoretic separations, and also on the different responses of microorganisms and of animals, indicated that a large number of different cobalamins occur naturally (5, 7, 9, 11, 15, 17, 21). Proof of the structure of vitamin B_{12} (2, 14) finally led to the conclusion that, while the vitamin itself contained the "nucleotide-like" residue 5,6-dimethyl-1-(α-D-ribofuranosyl)-benziminazole-3′-phosphate (1, 18), substitution of this nucleotide by certain other benziminazoles or purines would result in formation of a variety of different cobalamins (1, 7, 9, 11, 21). So far this substitution has only been accomplished microbiologically by incubation of naturally occurring (11, 12) or chemically prepared (1) Factor B, the nucleotide-free residue of vitamin B_{12}, with certain microorganisms in the presence of various benziminazoles or purines (11, 21). In a few instances the compounds formed have been isolated, purified, and chemically identified, but in most cases this has not been accomplished, the evidence for their presence being based purely on separation by paper chromatography or zone electrophoresis on filter paper, followed by development of "bioautographs".

[1]Manuscript received October 1, 1956.
Contribution from the Fisheries Research Board of Canada, Technological Station, Vancouver, B.C.

[2]Cobalamin in which the nucleotide residue is 5,6-dimethyl-1-(α-D-ribofuranosyl)-benziminazole-3′-phosphate.

The present work was undertaken to ascertain whether different cobalamins occur in marine invertebrates and in seaweeds, and the possible role of the natural bacterial flora of these marine forms on the synthesis of cobalamins. A brief report of preliminary studies has been published (23).

Materials and Methods

Chemical Preparations

The following compounds were used: riboflavin, adenosine-5′-phosphate, adenine, xanthine, guanine, thymine, uracil, ribonucleic acid (Nutritional Biochemicals Corporation); vitamin B_{12} (cyanocobalamin) (Merck & Co. and Nutritional Biochemicals); vitamin B_{12a} (hydroxocobalamin (Lederle Laboratories); vitamin B_{12c} (nitrocobalamin, prepared in this laboratory, see Smith (22)); 1,2-diamino-4,5-dimethylbenzene and 5,6-dimethylbenziminazole (Hoffmann-La Roche and Merck & Co.); pseudovitamin B_{12} (Parke, Davis & Company); benziminazole, 6-nitrobenziminazole, 2-aminobenziminazole, benzthiazole (Eastman Kodak); 2-thioadenine and 2,6-diaminopurine (California Foundation for Biochemical Research).

Factor B was first prepared from calf faeces (12) and was later purified by zone electrophoresis (15). It is regarded chemically as cyanocobalamin from which the nucleotide has been removed and is, presumably, the amide corresponding to the hexacarboxylic acid (1, 2) which has been prepared from vitamin B_{12}. So far it has apparently not been obtained as an analytically pure crystalline compound. In the present work this factor was prepared chemically. In a typical experiment, 10 mg. of crystalline vitamin B_{12} (Merck) was dissolved in 2 ml. of 70% perchloric acid and heated 4 minutes in a water bath at 60–65° C. The solution was cooled promptly, diluted with 3 ml. of water, and an excess of anhydrous sodium sulphate added. All the colored components of the mixture were extracted with several successive small portions of benzyl alcohol, and these were then displaced into a very small volume of water by adding two volumes of diethyl ether to the benzyl alcohol extract and shaking the mixture in a separatory funnel. The watery solution was evaporated to a very small volume in a rotary evaporator at 37° C. An electrophoretically and chromatographically homogenous preparation of Factor B was obtained by successive zone electrophoresis in 0.05 *M* phosphate buffer pH 6.5 containing 0.01% potassium cyanide (1), and in 0.05 *M* acetic acid containing 0.01% potassium cyanide (15); and finally by continuous paper electrophoresis (8) in 0.05 *M* acetic acid. The final eluate was concentrated to 10 ml. The absorption spectrum of the cyanide-free form exhibited maxima at 354, 498, and 528 mμ, and that of the dicyano form at 367, 540, and 580 mμ (1), and both spectra were similar to these shown by Gregory and Holdsworth (13). A yield of 4.85 mg. of Factor B was obtained as calculated from the optical density of a 1 in 10 dilution of the dicyano form at 367 mμ using the usual $E^{1\%}_{1\,cm.} = 210$ value of cyanocobalamin as an arbitrary standard (13). Factor B solutions in 0.01% potassium cyanide were stored at 0° C. in the dark.

Chromatography

A number of different solvent systems which have been suggested in the literature for separation of cobalamins by paper chromatography were used in initial work. A secondary butanol – acetic acid – water – cyanide solvent (13) proved most satisfactory. Control aqueous solutions of cobalamins containing 1 μg./ml. were prepared and 5 μl. spots were applied to Whatman No. 1 paper. Since many of the bacterial cell extracts (*vide infra*) contained comparatively low concentrations of cobalamins, it was found necessary to apply six successive 5 μl. portions to the paper with intermediate drying. The cobalamins were separated by descending development for 18 hours at 37° C. Though electrophoretic separation (15) was used in early experiments, it was found somewhat more cumbersome and did not yield more useful information than did paper chromatography.

Bioautographs

The medium employed and the conditions were similar to those described for a pad-plate assay for vitamin B_{12} (10, 16). One milliliter of a 16-hour vigorous broth culture of the *Escherichia coli* mutant 113-3 was used to inoculate 300-ml. portions of the molten assay medium which was then permitted to solidify in 30 × 45 cm. Pyrex dishes. The paper chromatograms, from which all solvent had been permitted to evaporate, were applied to the seeded agar. They were removed after 30 minutes, the dishes being incubated for 16–18 hours at 37° C. This method is very sensitive in that visible purple zones are formed where it is difficult to locate bacterial growth in absence of the indicator. The bioautographs developed in this manner were photographed by direct contact printing.

Results

Cobalamins in Seaweeds and Marine Invertebrates

In initial studies, numerous extracts were prepared from local seaweeds, clams, and oysters, employing a variety of methods. The results indicated that the seaweeds all contained vitamin B_{12} itself in comparatively low concentration. Only in one instance was there an indication of the presence of another form of the vitamin. This may have been because the sensitivity of the assay method employed was inadequate to detect the presence of possible very low concentrations of other cobalamins. On the other hand oysters, clams, and tube worms (*Eudystilia vancouverii*) contained comparatively high concentrations of vitamin B_{12} and of other cobalamins. Since clams yielded extracts of higher potency than the other invertebrates, they were used in detailed studies. Fig. 1 shows a bioautograph in which an aqueous, cyanide-containing (pH 6.4) extract of clam (*Saxidomus giganteus*) was compared with vitamin B_{12} (cyano-, hydroxo-, and nitro-cobalamins) and pseudovitamin B_{12} (7, 11, 17). In this experiment, since the solvent contained cyanide, all the three forms of vitamin B_{12} were converted to cyanocobalamin and therefore ran at the same rate, while pseudovitamin B_{12} ran much more slowly.

It will be seen that the pseudovitamin B_{12} preparation was not completely homogenous, and this verifies electrophoresis experiments (15). The clam extract gave four zones, one of which was apparently cyanocobalamin. Results of a number of other experiments, not reported here for sake of brevity, showed that extracts of different samples of clams (*S. giganteus* and *Paphia staminea*) and of oysters (*Ostrea gigas*) always contained not only vitamin B_{12} itself, but also a variety of other cobalamins which migrated more slowly in the solvent system used. At this time the publications of the Reading and Cambridge groups referred to above appeared, and the investigation was modified in order to study the formation of cobalamins by bacteria isolated from clams, and the role of Factor B and of various purines or benziminazoles in this formation.

Isolation of Bacteria

In general, the bacteria associated with clams appear to differ from those usually found in fish (25). One hundred cultures were obtained from clams by usual plating methods and all were grown in nutrient broth and then screened by the pad-plate method (16) to determine their ability to form vitamin B_{12}-active substances. It was found that, on repeated transfer in laboratory media for several weeks, many of the organisms appeared to lose their ability to form vitamin B_{12}-active substances, and only two of these

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NOTE: "Numerals" represent origins of the chromatograms. "Controls" indicate application of aqueous solutions of vitamin B_{12} or Factor B.

FIG. 1. A comparison of chromatograms prepared from different forms of vitamin B_{12}, from pseudovitamin B_{12}, and from a typical cyanide treated clam extract.
1. Clam extract
2. Pseudovitamin B_{12}
3. Vitamin B_{12c} (nitrocobalamin)
4. Vitamin B_{12a} (hydroxocobalamin)
5. Vitamin B_{12} (cyanocobalamin)

FIG. 2. Cobalamin formation by a *Bacillus* species after 64 hours' incubation in presence of Factor B and the following additives:
1. Factor B (control)
2. Factor B + ribose
3. Factor B + glucose
4. Ribose
5. Glucose
6. Factor B
7. Basal medium alone
8. Vitamin B_{12} (control)

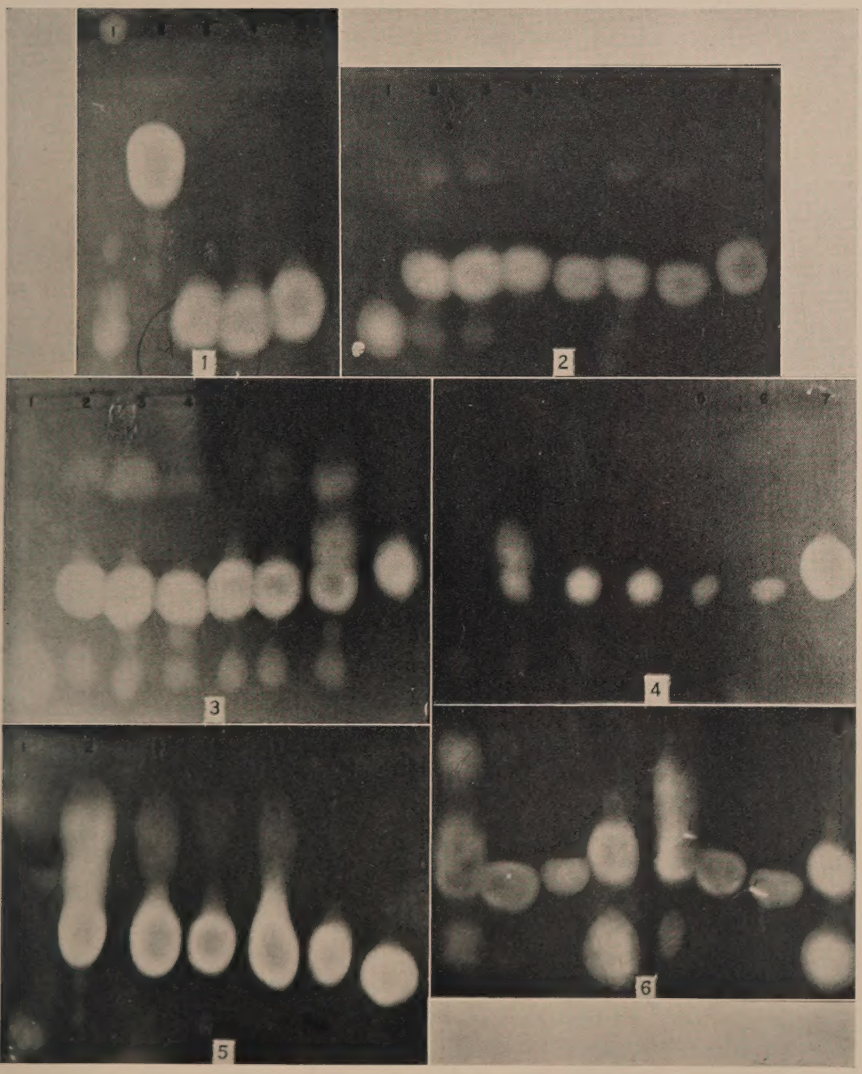
FIG. 3. As in Fig. 2 but with the following additives:
1. Factor B (control)
2. Factor B + riboflavin
3. Factor B + 2-thioadenine
4. Factor B + adenine
5. Factor B + benzthiazole
6. Factor B + 2-aminobenziminazole
7. Factor B + 6-nitrobenziminazole
8. Vitamin B_{12} (control)

FIG. 4. Effect of 6-nitrobenziminazole and other additives on formation of cobalamins by a *Bacillus* species after 24 hours' incubation:
1. Factor B (control)
2. Factor B + glucose + 6-nitrobenziminazole
3. Factor B + glucose
4. Factor B
5. Glucose
6. Basal medium alone
7. Vitamin B_{12} (control)

FIG. 5. Effect of 6-nitrobenziminazole on formation of cobalamins by a *Bacillus* species after 144 hours' incubation. Additives as in Fig. 4.

FIG. 6. Effect of 6-nitrobenziminazole on formation of cobalamins by a *Micrococcus* species after 72 hours (Nos. 1–4) and after 192 hours (Nos. 5–6) with the following additives:
1 and 5. Factor B + glucose + 6-nitrobenziminazole
2 and 6. Factor B + glucose
3 and 7. Basal medium
4 and 8. Vitamin B_{12} and factor B (mixed control)

PLATE I



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which proved most active were selected for detailed study. Classification (3) indicated that one of these organisms closely resembled *Micrococcus pyogenes* var. *aureus*, and that the other was a *Bacillus* species.

The formation of cobalamins by these organisms when cultivated in the presence of Factor B and various benziminazoles or purines was investigated. Still cultivation was used since cultivation on a rotary shaker at 20° or 25° C. failed to increase cobalamin formation. Both organisms grew at 0° and at 10° C., but since growth and cobalamin synthesis was more rapid at 25° C., this temperature was used. It was found that washed cells of the organisms occasioned no apparent cobalamin synthesis in 24 to 72 hours in phosphate buffer, pH 6.7, in the presence of Factor B and 5,6-dimethylbenziminazole or 1,2-diamino-4,5-dimethylbenzene.

Cobalamin Formation with Bacterial Isolates

The organisms were grown in 50 ml. portions of Burkholder's medium (6) in 500 ml. conical flasks at 25° C. Factor B and the various compounds were added to the medium in 1 μg./ml. concentration. Since the cobalamin activity was found in the bacterial cells, the organisms were collected by being centrifuged at 6000 *g* and extracted with hydrochloric acid in the presence of cyanide (11), thereby ensuring that all cobalamins would be in the cyano form. In a number of different experiments it was found that 5,6-dimethylbenziminazole, riboflavin, adenine, 2-thioadenine, benziminazole, 2-aminobenziminazole, and 6-nitrobenziminazole caused formation of cobalamins which differed chromatographically from vitamin B_{12} itself, and that these cobalamins were always formed in greater amount in the presence of these compounds than when Factor B alone was added to the medium. Adenosine-5-phosphate, thymine, guanine, uracil, xanthine, ribonucleic acid, 2,6-diaminopurine, and 2,3-diamino-4,5-dimethylbenzene did not support formation of cobalamins other than vitamin B_{12} from Factor B.

Figs. 2 and 3 illustrate the formation of various cobalamins by the *Bacillus* species when cultured 64 hours in both the presence and absence of Factor B and various additives. From Fig. 2 it is apparent that in all instances the organism occasioned disappearance of Factor B with an increase in vitamin B_{12}. Small amounts of a slow-moving cobalamin were present in all inoculated media containing Factor B, and even in the medium without any additive. When glucose or ribose was added without Factor B the amount of this slow-moving factor formed was almost negligible. In Fig. 3 are recorded the results obtained by cultivating the *Bacillus* in media containing Factor B plus glucose and six different compounds, and, for these, No. 3 (Fig. 2) should be used as the control. They show that, with the probable exception of benzthiazole, all compounds stimulated formation of cobalamins other than vitamin B_{12} with a decrease in the amount of Factor B. With 6-nitrobenziminazole several different growth zones formed, indicating the presence of several cobalamins.

In view of the above finding, subsequent work with this organism was carried out using 6-nitrobenziminazole. From Fig. 4 it will be seen that

only when Factor B plus 6-nitrobenziminazole and glucose were added to the medium were significant amounts of cobalamins other than vitamin B_{12} formed after 24 hours. After 144 hours (Fig. 5) the picture had altered considerably, for a slow-moving cobalamin was present in several of the media containing Factor B, glucose, or glucose plus Factor B, but the amount of this cobalamin was considerably greater in the medium containing 6-nitrobenziminazole.

In view of the results with the *Bacillus* an experiment was carried out with the *Micrococcus* in which 6-nitrobenziminazole was the only substance investigated. The results, shown in Fig. 6, indicate that only when this compound plus glucose and Factor B were present in the medium were significant amounts of cobalamins other than vitamin B_{12} formed. With this organism there was no apparent difference in the approximate amount of cobalamin after 72 and 192 hours.

Discussion

Observations made in this and in other laboratories have indicated that marine forms of life are usually relatively good sources of cobalamins. Since these are very largely formed in nature by microorganisms, a preliminary study of their occurrence in some seaweeds and marine invertebrates has been made. The results showed that vitamin B_{12} itself was present in all forms tested, and moreover, that a large proportion of the cultures which were isolated formed this vitamin. On the other hand, various forms of cobalamins which moved more slowly than did vitamin B_{12} itself were present. In the present experiments Factor B was never detected in clam or bacterial cell extracts, and in this respect these materials appear to differ from extracts of calf faeces, rumen contents, and of vitamin B_{12}-requiring *E. coli* mutants.

The present work shows that the formation of cobalamins other than vitamin B_{12} itself may occur extensively in marine forms of life, and that bacteria isolated from these utilize Factor B in the formation of vitamin B_{12} and of other cobalamins. With the organisms studied 6-nitrobenziminazole was found to be the most active of a number of purines and benziminazoles investigated in occasioning formation of vitamin B_{12} and other cobalamins from Factor B.

Since the actual quantities of cobalamins formed in experiments such as the above are extremely small, no attempt has yet been made to concentrate or isolate them, and the data available on R_f values are hardly reliable enough in themselves to warrant any attempt at distinction. It is highly probable that a single bacterial growth zone arising from a chromatogram may represent two or even more cobalamins. The mechanism by which benziminazoles or purines combine with Factor B to form cobalamins is not clear. It is possible that the substance is first phosphorylated by a phosphorylase enzyme in the presence of ribose-1-phosphate to form a purine or benziminazole nucleoside which yields the corresponding ribotide with adenosine triphosphate in the presence of a kinase enzyme. Certainly the parent nucleotide of vitamin

B_{12} itself forms vitamin B_{12} when incubated with *E. coli* and Factor B (11). Apparently nothing is known yet regarding the enzyme mechanism which might be involved in linking the phosphate group of the nucleotides to the aminopropanol residue of Factor B, nor the possible role of β-ribotides in replacing the α-ribotide occurring in vitamin B_{12}.

Acknowledgment

We are indebted to the following firms for kindly providing certain of the organic compounds employed: Lederle Laboratories; Merck and Company; Parke, Davis and Company, and Hoffman-La Roche; and to Messrs. E. G. Baker and J. W. Boyd for the photographs.

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Antibiotic Residues in Fish Iced with Chlortetracycline Ice and Effect of Normal Cooking Procedures on These Residues

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Isochlortetracycline, a substance that is inert or practically inert bacteriostatically, is formed when chlortetracycline (CTC) is treated with alkali[6] or when flesh foods containing it are heated.[10] However, fish muscle and various natural colloidal and other substances retard this change,[2, 6] and consequently some consideration has been given to the problem of CTC residues in cooked flesh foods. In general, the antibiotic activity of CTC disappears more rapidly at 37 or 100 C. in buffered aqueous solutions between *p*H 2.5 and 9.0 than does that of oxytetracycline or tetracycline.[3] Some information is already available regarding the rate of inactivation of CTC during heating of flesh food, such as might occur in normal cooking procedures. Thus, studies with minced salmon and beef held in beakers in water at 100 C. indicated that only about one third of an initial concentration of 5 μg./Gm. of CTC remained after 15 minutes.[11] Further investigation using fish muscle samples into which thermocouples were inserted showed that roughly 80 per cent of added CTC (6.5 and 16 μg./Gm. in two different experiments) was inactivated in five minutes at 60 or 80 C., and 95 per cent in five minutes at 99 C.[9, 10] From 89 to 95 per cent of added CTC was destroyed in five minutes in chicken muscle in boiling water (100 C.),[5] and the rate of destruction was similar in chicken cooked five minutes at 120 C.[4] Previous work has shown that only very small residual amounts of CTC can be found in exposed portions of gray cod (*Gadus macrocephalus*) iced with ice containing CTC for about 10 days.[9] In the present study, CTC residues in fresh gray cod iced with CTC ices containing 2 and 4 μg. Gm. of the antibiotic, and the effect of normal cooking procedures on these residues, have been determined. These species of fish were selected for study since "fictitious" assay results are rather rarely experienced with them.[9, 10] Data are also presented regarding CTC residues in the flesh and liver of whales treated with this antibiotic.

CTC RESIDUES IN UNCOOKED AND COOKED FISH FILLETS

In a first experiment fresh noneviscerated gray cod were stored in ordinary ice and in crushed block ices containing 2 and 4 μg. Gm. of CTC as determined by microbiologic assay. At stated intervals, fish were removed, filleted, and the fillets (skinned and unskinned) cooked by immersing them 10 minutes in boiling water, baking 10 minutes in an oven at 247 C. (475 F.), or frying about five minutes in cottonseed oil.[1] The cooked samples were promptly wrapped in aluminum foil, frozen in solid carbon dioxide, and stored at −20 C. for a period not exceeding two weeks. Extracts of the raw flesh were prepared by thawing the fillets, blending

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a portion with an equal volume of water, adjusting the *p*H of the suspension to 4.6 with 1.0 *N* hydrochloric acid, and centrifuging at 10,000 gravity in a refrigerated centrifuge at 0 C. For some cooked fillets it was necessary to add only one tenth the volume of water to obtain a suitable extract.

In a second experiment gray cod were selected at random from fishing vessels that had alternately carried ordinary ice and ice containing 2.5 μg./Gm. of CTC. The fillets from these fish were wrapped in polyethylene and stored at −20 C. for a period not exceeding two months. Since they were partially frozen when cooked, the cooking periods were extended to 20 minutes before extracting as in the foregoing experiment. Aqueous extracts (*p*H 4.6) were prepared as in the first experiment.

The CTC present in the extracts was determined by a pad plate microbiologic method [1] with a few slight modifications. For the standard curve, CTC hydrochloride was dissolved in gray cod muscle extract (*p*H 4.6) prepared as previously described, the range of concentrations used being from 0.0015 to 0.05 μg. for 12.7 mm. assay pads. Since each pad received 0.1 ml. of extract, the method was usually sensitive to 0.015 μg./ml. of CTC, though with some assays the limit of sensitivity was 0.03 μg./ml. of CTC. The brain-heart infusion agar medium used was adjusted to *p*H 5.5.

The results of the first experiment (table I) show that the CTC concentration in uncooked fillets tends to increase with storage time in ice and is, as might be expected, greatest in unskinned fillets. However, even in these fillets the highest concentration that occurred after 10 days' storage in ice containing 4 μg./Gm. CTC was 0.6 μg./Gm. Since the coarse skin of fish is rarely consumed and has little nutritive value, the highest concentration found in the skinned fillets (0.1

TABLE I

CTC Residues in Flesh of Gray Cod Iced with CTC Ice and Effect of Cooking on These Residues

Days stored in ice	Concentration CTC in ice, μg./Gm.	Residual CTC in fresh gray cod fillets after cooking, μg./Gm.					
		Uncooked		Baked		Boiled	
		Skinned	Unskinned	Skinned	Unskinned	Skinned	Unskinned
3	0	0	0.02	0	0.02		0
	2.0	0.03			0		0
	4.0	0.06	0.15		0.08		0
5	0	0.07		0.07			0.05
	2.0	0.10	0.18	0.07	0.07	0	0.03
	4.0	0.10	0.23	0.05	0.13	0	0.07
7	0		0		0	0	
	2.0	0	0.06	0	0.03	0	
	4.0	0	0.20	0	0.05	0	0.03
10	0		0		0		0
	2.0		0.31		0.08		0.06
	4.0		0.60		0.38		0.30

Table II

CTC Residues in Cooked Fillets of Gray Cod That Had Been Iced on Commercial Vessels with Ice Containing 2.5 μg./Gm. of the Antibiotic

Days in ice	Residual CTC in frozen gray cod fillets after cooking, μg./Gm.		
	Boiled	Baked	Fried
6	0	0.08	0.04
7	0	0	0.17
	0	0	0.12
8	0	0	—
12	0	0.04	0

μg. Gm.) can probably be considered more representative of concentrations of CTC that might occur in the "edible" portion of raw fish iced with CTC-containing ice. The results of both experiments (see also table II) indicate that boiling removes all assayable CTC in skinned fillets and usually most of that present in unskinned fillets. Very small and variable concentrations of CTC (e.g., 0.02 to 0.13 μg. Gm. with a single exception) occurred in unskinned and skinned baked fillets (tables I and II) and in fillets fried in mineral oil (table II).

The CTC residues found in unskinned raw fillets from fish iced with ice containing 4 μg. Gm. CTC in the present experiments are similar to those recently reported in the literature.[7]

CTC RESIDUES IN WHALE TISSUES

In continuation of previous experiments, 50 whales (finback, humpback, sperm, and sei whales) were treated by injecting into their visceral cavities postmortem 100 Gm. of CTC hydrochloride dissolved in 10 gallons of sea water.[5, 10] Samples of muscle and liver were obtained at the time of processing, placed in polyethelene bags, promptly frozen, and stored at about −20 C. until they could be examined conveniently (a period not exceeding two months). These samples are being assayed for their CTC content by the same method used for the fish samples; typical results with finback whales are given in table III. They indicate that only very low CTC concentrations occurred in the tissues examined, and that in quite a large proportion of them no CTC could be demonstrated.

Table III

Distribution of CTC in Treated Whale Tissues

Portions assayed	Concentration of CTC in samples from a number of whales, μg./Gm.
Muscle near backbone	0.08, 0.06, 0.07, 0, 0, 0.06, 0.07
Muscle near throat	0, 0, 0.04, 0.1, 0, 0, 0.08, 0.05, 0
Muscle adjacent to blubber	0, 0.06, 0, 0.07, 0, 0
Liver	0.1, 0.26, 0, <0.08

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THE *CALANUS* EXPEDITIONS IN THE CANADIAN ARCTIC, 1947 TO 1955

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Reprinted from

"ARCTIC"

Journal of the Arctic Institute of North America
Volume 9, Number 3, 1956

THE *CALANUS* EXPEDITIONS IN THE CANADIAN ARCTIC, 1947 TO 1955*

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The recently reorganized Arctic Unit of the Fisheries Research Board of Canada, with headquarters at McGill University in Montreal, is a development of the Eastern Arctic Investigations that began in 1947. The *Calanus*, a diesel ketch of 43 tons, was built in Nova Scotia in 1948 (Dunbar, 1949); her name has been taken to cover all the field work of the series, including the seasons of 1947 and 1948 before the *Calanus* was used, and the work of individual members of the staff not attached to the ship.

The work done on the *Calanus* expeditions consists of the collection of material for the study of the abundance, distribution, and breeding cycles of sea mammals, fishes, plankton, and benthos. The emphasis has varied from season to season according to the particular nature of the region of operation and in relation to the needs of development and improvement of Eskimo economy. More time has been spent on mammals, especially walrus, ringed seal and beluga from 1953 to 1955. Collections of plankton and benthos were only qualitative in the first years. Quantitative work on both was begun in Frobisher Bay in 1951, and since 1954 efforts have been made to attack the problem of the rate of production of organic material in these cold arctic and subarctic waters. Physical oceanographic observations, including hydrographic sections, have been made on all expeditions. Oxygen concentrations have been measured since the start of operations, and phosphates since 1951.

The results so far available, whether published or not, are summarized below, following a brief account of the area of work, personnel, and logistics of each year's expedition. Station lists for all years to 1954 incl. have been published (Dunbar and Grainger, 1952; Grainger 1954b; Grainger and Dunbar, 1956).

1947. A reconnaissance of Ungava Bay was carried out by the author, assisted by H. Hildebrand, then a graduate student at McGill. Students have been employed as summer assistants every year, and the training of young men in northern work has been an important part of the programme. The party worked the coastal waters of the bay from Payne Bay to Koksoak River in a 30-foot "trap-boat" during the first half of the summer. In the second half work was done in the eastern part of the bay, from Koksoak River to Port Burwell in a 40-foot native-owned Peterhead boat.

*This paper does not mention arctic and subarctic work of the Fisheries Research Board before 1947. The northern work began in 1944 in northwestern lakes and rivers. (*See* F. R. B. Bulletin No. LXXII.)

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1948. Hildebrand worked on two lakes in the vicinity of Fort Chimo in March and April to obtain information on freshwater conditions in the winter.

Hildebrand and Ph. Orkin accompanied an Eskimo hunting party during late June and early July to work on ringed seal (*Phoca hispida*) and bearded seal or squareflipper (*Erignathus barbatus*). The second half of the summer was spent in the vicinity of Port Burwell, the work there being concerned mainly with the Atlantic cod (*Gadus callarias*).

E. H. Grainger was attached to a commercial fishing venture as observer, in order to begin a study of the arctic char (*Salvelinus alpinus*) at the head of Frobisher Bay. The *Calanus* was built during this summer and was sailed north to Fort Chimo by Ernest Ritchie, with W. E. Wilson (engineer), Kingsley Morisson, and Constable Hayley of the marine section of the R.C.M.P. Hayley replaced Dunbar, who was invalided ashore at Halifax. The boat was beached at Chimo, using cradle and winch.

1949. This was the first season in which the *Calanus* was used in field work. The ship's company consisted of Dunbar, Grainger, Wilson, T. Creery, E. Reid, and two Chimo Eskimo. The boat was launched on June 16 and entered Mission Cove harbour at Burwell on June 29. The eastern half of Ungava Bay is always clear of ice before the western. Hydrographic sections were made across the bay, using Akpatok Island as the hub. The Button Islands were visited and a considerable part of the season was spent at Port Burwell.

1950. The work in Ungava Bay was continued, with emphasis on experimental fishing, especially for Greenland shark (*Somniosus microcephalus*). Some time was spent in the vicinity of Cape Hope's Advance and Diana Bay (which had been visited also in the previous year), and a section was made across Hudson Strait from Wakeham Bay to Big Island. Work at Burwell and in the Button Island group was continued. On another project, J. Wright accompanied the same commercial fishing venture that Grainger had joined in 1948, working on the arctic char in Frobisher Bay and on the Atlantic cod at Resolution Island (Acadia Cove). A. H. Lawrie accompanied the U.S. Navy Resupply Mission to the far northern stations as observer for the Fisheries Research Board. The *Calanus* was again beached at Chimo for the winter, as in the two previous years.

1951. With Dunbar, Lewis, I. McLaren, W. E. Wilson and T. E. Wilson on board, the *Calanus* spent a few weeks in the eastern part of Ungava Bay, paying special attention to the little fiord of Adlorilik. She then crossed Hudson Strait to Lake Harbour and arrived at the Frobisher R.C.A.F. base on August 1. The month of August was spent entirely within Frobisher Bay, carrying out an elaborate series of sounding runs, dredging, trawling, and plankton hauling. The ship was beached at the Frobisher air base.

Grainger spent the season at the Sylvia Grinnell River in Frobisher Bay, making an intensive study of the arctic char. Lawrie took part in the *Cancolim II* expedition into the Beaufort Sea in the western Arctic as marine biologist for the Board. This was the first extension of the field of operations into the West.

1952. Grainger, McLaren, W. F. Black, T. E. Wilson, and an Eskimo pilot took the *Calanus* into Cumberland Sound. The working season was cut short by mechanical trouble and the party had to return to Frobisher for temporary repairs, after which the ship was taken at reduced speed to Churchill for repairs and wintering. J. Martin and S. McCall joined the ship's company for that trip. Some of the roughest weather of any of the expeditions was encountered on this voyage together with further mechanical trouble and Grainger's party did exceedingly well to bring the crippled *Calanus* safely into Churchill harbour.

McCall and A. Dawson had been working during the summer on Ogac Lake on the southwest shore of Frobisher Bay, in which exists an isolated population of Atlantic cod (see page 184). This work was supported by the Carnegie Arctic Fund of McGill University, but the results will be incorporated in due course into the *Calanus* expedition series.

1953. For the work in Hudson Bay, which is a very large inland sea, a professional skipper was engaged for the first time. This post was filled in 1953 by R. Collyer. Grainger was again in charge of the scientific work and assisted by McLaren, Black and Dawson. The field work covered northern Hudson Bay and the western end of Hudson Strait, and a beginning was made in the study of the northern Hudson Bay herd of walrus (*Odobenus rosmarus*) that is to be found in summer first at Walrus Island, then at Bencas Island and the northern end of Coats Island, and still later at Seahorse Point, Southampton Island.

1954. Captain H. Norden Andersen took over as skipper, with Wilson still as engineer. The scientific party consisted of Dunbar, Grainger, and J. A. Thomson. The field work was very largely on the walrus at Walrus Island, Bencas Island, and Coats Island. Grainger spent several weeks at Coats Island with two Eskimo tagging walrus and collecting material. Thomson left in August and the remainder of the party sailed the ship to Montreal, where she was given her first refit. She was fitted with a new magnetic compass, a Sperry gyrocompass, a new and more powerful radio, a new auxiliary engine, and a set of hydraulic winches from Scandinavia (main trawl winch, hydrographic winch, and anchor windlass). All hatches were renewed and rearrangements made in the space below decks.

McLaren spent the period from March to October in the Cape Dorset area of Baffin Island, making a thorough study of the ringed seal. Dr. F. Neave, of the Nanaimo, B.C., Station of the Fisheries Research Board, accompanied an ice-breaker and supply mission in the Beaufort Sea, to make a reconnaissance of fisheries research needs in that region.

1955. The *Calanus* left Montreal at the end of June with Andersen, Grainger, McLaren, Black, and Wilson on board; Dawson served as supernumerary as far as Battle Harbour, Labrador. The ship was greatly delayed by unusual ice conditions on the Labrador coast; this provided opportunities for some interesting work on plankton production, and on cod at Nain. The late arrival at Coral Harbour made it necessary to abandon the work planned for the southeastern part of Hudson Bay. The party was joined at Coral

Harbour by A. Mansfield, who had been working from there on walrus since late March, on a grant from the McGill Carnegie fund. The work of 1954 at Coats Island was continued. Wilson left early in September, and Mansfield continued his work on walrus by accompanying an Eskimo hunting party to Seahorse Point and returned to Montreal in October. The remaining four took the ship through Roes Welcome Sound and Frozen Strait to Igloolik, where she was frozen-in in October. Black and McLaren left a little later for Montreal, leaving Andersen and Grainger as wintering party on board. A winter station was established through the ice in some 50 metres of water in Foxe Basin for the observation of the winter regime in plankton and benthos, and work began at the same time on walrus and ringed seal; northern Foxe Basin is one of the few places where walrus are known to winter.

D. Sergeant spent the summer studying the beluga (*Delphinapterus leucas*) in the area of Churchill, where a commercial company has a license for the limited exploitation of the beluga. Material from 200 whales was collected with the aid of a whaleboat. The *Calanus* group now has two powered whaleboats in commission, one at Coral Harbour, the other at Churchill.

J. G. Hunter, attached to the Nanaimo Station, joined the group in 1955 in order to begin work on the fishes of the coast of Beaufort Sea from Herschel Island to Baillie Island, studying the fully marine, as well as the anadromous species. The chief purpose of this work is to establish the biotic potential of these fishes, with a view to a rational development of native fisheries.

The author was in charge of these investigations from 1947 to 1955 on a part-time basis. They have now grown so large that full-time control is essential. In 1954–55 the group was reorganized and the staff considerably enlarged. Dunbar remains as consultant and adviser, and the present full-time staff is as follows:

Dr. H. D. Fisher (in charge)	Mr. A. W. Mansfield
Dr. E. H. Grainger	Miss B. M. Barry
Dr. D. E. Sergeant	Captain H. N. Andersen
Mr. J. G. Hunter	Miss L. McMullen
Mr. A. S. Bursa	Miss J. Thompson
Mr. I. A. McLaren	Mr. T. E. Wilson

Captain Andersen, who has had five years' experience with schooners on the west coast of Greenland, is skipper of the *Calanus* and general technical assistant. Miss L. McMullen is secretary and general assistant to Dr. Fisher.

Summary of results

Physical oceanography

The map Fig. 1 shows the hydrographic sections made up to 1954, and the waters covered in the field work. Sections in Ungava Bay show a flow of water into the bay from the northwest, across its central part south of Akpatok Island, and out in the northeast, this last flow being pressed against the Labrador side. Akpatok Island sits on a shelf extending eastward from the island (which is of Palaeozoic limestone, in contrast to all the rest of the

Fig. 1. Hydrographic sections and working areas of the *Calanus* expeditions.

Ungava Bay rocks), and there is a trench with depths of over 200 metres surrounding this formation. No good trawling bottom was found in the bay; the bottom is exceedingly uneven and apparently boulder-strewn. The water is of low temperature and of low salinity, but the upward trend of these two parameters that is commonly encountered at depths below 200 metres probably indicates the entry of Atlantic (West Greenland) water into Ungava Bay at these depths. The upper water of the bay shows great dilution by land drainage, and Atlantic influence is not demonstrable from hydrographic data; admixture of Atlantic water is, however, strongly suggested by the plankton, which is subarctic rather than arctic (for the criteria used to delimit the two marine regions see the paper on the Ungava amphipods (Dunbar, 1954)), by the amphipod fauna, and by the presence of two fishes, namely the Atlantic cod in the northeast part of the bay, and the Atlantic salmon (*Salmo salar*) in the rivers of the eastern and southern shores, as far west as the Koksoak.

Mixing of the waters of Ungava Bay and also of Hudson Strait and Frobisher Bay appears to be facilitated by the establishment of density inversions, probably for short periods of time only. Density inversions, which are not yet fully accepted as respectable by the oceanographic world, began to appear in the *Calanus* results from 1949 onward, and there is evidence that they are associated with strong tidal currents and large tidal intervals (Dunbar, 1955).

Exceptional hydrographic conditions were found in Adlorilik, a small fiord on the eastern side of Ungava Bay. This is an inlet that is well over 100 metres deep and that has a very shallow sill at the entrance. In contrast to the usual conditions in such fiords in the North, as in Victoria Bay on the shore of Frobisher Bay or in fiords in Greenland, where the deep water inside the fiords is much colder than the water at similar depths outside the fiords, the deep water of Adlorilik was found to be very much warmer than the corresponding water outside (3°C. at 80 metres inside compared with 1.2°C. outside). Possibly this is a wind effect.

From the sounding runs made in Frobisher Bay in 1951 an interesting pattern was brought to light, the two main features of which are (1) a deep trough along the southwest side of the bay, extending from a fairly low threshold at the mouth (about 275 metres) to the islands that separate the outer and inner bays; this trough is often deeper than 550 metres, and sometimes deeper than 640 metres, which is beyond the limit of the sounder scale of the *Calanus*; (2) a shelving bank in the northeast half of the outer bay extending from the level of Wiswell Inlet to at least as far as Loks Land. This bank, now known as the "Calanus Shelf", slopes gently from very shallow depths near the shore to some 130 metres before meeting the deep trough already described. Bottom temperatures over this shelf were of the order of -0.5°C. in 50 metres in August 1951, and trawling over the shelf as a whole gave very poor results.

Fishes

The collection of fishes from Ungava Bay has already been published (Dunbar and Hildebrand, 1952), and only features of the fish fauna that are of zoogeographical interest are referred to below. Special attention has been given to the Atlantic cod of the Port Burwell area and to the arctic char of Frobisher Bay. These two species, together with the Greenland shark, and perhaps the Greenland halibut (*Reinhardtius hippoglossoides*) form the small group of fishes which offers possibilities of development in the interests of the Eskimo economy in restricted localities of the Eastern Arctic. The shark is easily caught wherever seals are abundant along the eastern shores of this region, at least from Cape Chidley and Burwell to northern Baffin Island; it does not appear to be common in Hudson Strait or in Frobisher Bay.

The Atlantic cod arrives at Burwell in late July or early August and leaves again in September-October. During that short period, however, large numbers are present, and it can be taken at the rate of about 20 fish per

man-hour. Long-lining was not successful at Burwell, perhaps owing to the shortage of good bait. Burwell is the only region in the whole of the Canadian Eastern Arctic, except the Labrador coast, that offers a cod fishery. The fish are small and the rate of growth is slow, a 60-cm. specimen being 12-13 years old. The possibility of developing a fishery in Ungava Bay has been discussed elsewhere (Dunbar, 1952).

A study of the biology of the arctic char, as regards its breeding cycle, growth rate, and sea-life, has been published by Grainger (Grainger, 1953), who has shown that the char of the Sylvia Grinnell River, at the head of Frobisher Bay, can reach an age of more than 24 years and a length of approximately 70 cm. The first migration to the sea occurs probably during the fifth to seventh summer, and the sea-life each year lasts from late June to late July or early September. The females reach sexual maturity at a length of about 54 cm. and an age of about 12 years. Egg counts of maturing fish averaged 3,590, and apparently only one third of the females over 12 years breed in any one year. From these results, and without yet knowing the mortality of the young in fresh water, it was concluded that the char population of a single stream could be seriously damaged by intensive fishing, especially on a commercial scale. At the same time it became clear that many char streams were not touched at all by the Eskimo, and that almost no effort was made to preserve the fish caught. The key to the development of this important resource lies, therefore, in providing greater mobility of the Eskimo and in encouraging the preservation of the char for winter use by smoking, salting, or freezing.

Ogac Lake, a small lake on the southwest shore of Frobisher Bay, has long been known to contain cod. The *Calanus* expedition of 1951 found that these are *Gadus callarias* and that they live completely isolated from the main marine population of cod. Atlantic cod are not known from Frobisher Bay itself, or from anywhere north of Resolution Island in the Canadian Eastern Arctic. The cod of Ogac Lake live in a layer of water of about 26.00‰ salinity or less and of temperatures of the order of 7-8°C., which is far above the temperature of the water in the adjacent fiord (Ney Harbour). This stratum lies between fresh water at the top and stagnant salt water at the bottom. There is contact with the fiord water at spring tides, but the cod apparently do not pass over the sill out of the lake. Fish of all sizes were taken in the lake, including large individuals of over four feet in length. The vertebral count is very low (51-52), indicating development in warm water. This cod population may have invaded the lake during a past period of warmer climate, at a time when cod were normally present in Frobisher Bay in summer.

Marine mammals

Walrus The walrus herd of northern Hudson Bay frequents in summer Walrus Island, Bencas Island, Coats Island, and Seahorse Point on Southampton Island, in that order, appearing at Walrus Island in July and at Seahorse Point in late August and September. Possibly some of them go south to the Belcher Islands during that period. An estimate of the numbers in the herd

is difficult to make at this stage; the present estimate is 3,000 animals. For the groups seen a ratio of one first-year young to every ten adults and adolescents was inferred. Of 18 specimens taken in 1954 five were males and 13 females. Of the females one was first-year, one second-year, two had newly-born young, and four were pregnant.

As a preliminary experiment, 23 walrus were tagged in 1954 with a new stainless steel tag designed by the writer (Fig. 2). The tag is about 1½ inches long and is designed to pierce the very tough hide, and lodge with the head in the layer of blubber and the basal disc on the outside of the skin. In 1955, 48 animals were marked, and the tagging is to be continued on a larger scale.

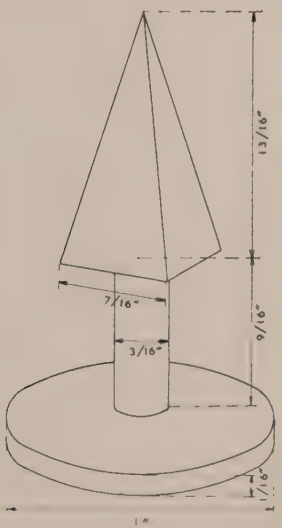

Fig. 2. *Calanus* walrus tag (stainless steel).

The walrus haul out on rocks of a certain shape that is not found everywhere in the north. Much of the shore-line is either very steep or very flat and not suitable for walrus. They prefer a sloping rocky shore that rises in terraces or otherwise unevenly to some few tens of feet above the water level. Since no significant difference was found between the benthonic food supply close to these rocks and the supply in other areas, it was concluded that an important factor in determining the walrus distribution in the summer may well be nothing more complex than the conformation of the shore. The winter distribution of this herd is still unknown; the tagging is expected to shed light on this.

Ringed seal. The *Calanus* has worked in areas rich in seal only since 1951. Intensive work on the ringed seal began at the western end of Hudson Strait in 1953. In that year, McLaren's material consisted of 44 animals. In 1954, working at Cape Dorset from March to October, he collected material from 498 specimens. Some of the results of this work, which will be published shortly, may be summarized as follows (McLaren, 1955):

The ringed seal is not a truly migratory animal and it appears that the decisive factor governing its distribution in the Arctic is the duration of the ice cover. This is formed earliest and persists longest along irregular coasts with much skerry development, and there appears to be a correlation between the pattern of the coast line and the seal distribution. By far the most important food organism, especially in offshore waters, is the pelagic amphipod *Themisto libellula*, but it is clear that the distribution of this crustacean has little to do with the distribution of the seal. In shallower inshore waters, seals feed to a large extent on decapod crustaceans, Mysids, and polar cod.

The study of the teeth of the ringed seal has shown that the fact that this species is a solitary form, and not a migratory and harem-breeding species, complicates the interpretation of the tooth-sections, since there tends to be a wide range of nutritional histories. The oldest individual, a male, was a little over 40 years old; very few were more than 20-25 years old. The male does not mature on the average until the seventh year; most of the females ovulate for the first time when about six years old, although a few may do so in their fifth year. "Testis histology reveals that the males are capable of fertilizing from late March until at least mid-April and that they are out of rut by late May and probably earlier. The females normally ovulate shortly after parturition, during lactation. Mating probably occurs shortly after the birth of the young. The young adult females may tend to be polyœstrous; older seals, possibly by fixation of the œstrous cycle through pregnancy, probably lose this tendency. . . . . The blastocyst remains unimplanted for a period of more than three months and individual embryos may implant over a period of about one month. . . . . The peak of pup production probably occurs near the beginning of April and the females may attend the young until mid-June, or later in some cases." (McLaren, 1955).

Beluga. A preliminary survey of the white whale population of western Hudson Bay was carried out by the Central Station of the Fisheries Research Board, when a license for commercial exploitation at Churchill was first granted (Doan & Douglas, 1953). Sergeant, of the Arctic Unit staff, began a thorough study in 1955 and examined 200 individuals. By aerial reconnaissance 2,700 white whales were counted on July 25; 900 in the Churchill River estuary and 1,800 near the mouth of the Seal River. By August 30 the whales had left the estuaries and were presumably on migration. A whale tag that is to be fired from a crossbow and which lodges in the blubber has been developed and will be used in 1957. Work is planned also on the beluga of the Mackenzie Delta.

Zoogeography and systematics

In the large-scale marine zoogeography of the north, the delimitation of a subarctic from an arctic marine zone has already been proposed by the author (Dunbar, 1954), and this system is used in discussing the present expedition results. The *Calanus* has worked so far on the northern fringes of the subarctic zone (Ungava Bay, Frobisher Bay, and Cumberland Sound),

and in the special region of Hudson Bay. Hudson Bay, although definitely outside the subarctic waters on the criteria used here and showing many of the characteristics of the arctic zone, nevertheless has to be placed in a category by itself on account of the high temperatures and low salinities in the upper layers in summer (up to 10°C. and down to about 23.00‰), a result of freshwater influx and very high stability, and on account of the preservation of warmer-water relicts, such as the caplin (*Mallotus villosus*) and the calanoid copepod *Acartia clausi*.

It has been established as a general rule that in the arctic zone the macronecton is dominated by mammals, with the fishes of minor importance and represented by comparatively few species, but that in the subarctic zone the macronecton is made up almost entirely of fishes, with the mammals relatively unimportant.

The northern limits of the distribution of the fishes of economic importance in the north, that is to say, of all fishes produced in large numbers, occur either close to the northern edge of the subarctic or well within it. The Greenland shark and the arctic char are the only exceptions, and the latter is an anadromous fish with a very short sea-life. The reasons for this striking distributional pattern are not clear, but they are no doubt connected with the different capabilities of homoiothermous and poikilothermous animals, and possibly with the time required for the adaptation of large poikilotherms to very cold environment.

In general faunistic and systematic studies, work in the following groups has been done, some of which has already been published: Fishes of Ungava Bay (Dunbar & Hildebrand, 1952); amphipods of Ungava Bay (Dunbar, 1954); polychaetous annelids (Grainger, 1954a); echinoderms (Grainger, 1955); cirripedes (Bousfield, 1955); priapulids, sipunculids, and pycnogonids of Ungava Bay, eastern Hudson Strait, Frobisher Bay, and Cumberland Sound; and the plankton copepods of Ungava Bay (Fontaine, 1955). Among the benthonic forms, including fishes, are many new records for the area and several for North America, and there are five new species of amphipods. The zoogeographic affinities of the fishes, annelids, echinoderms, and amphipods are as follows:

Fishes: 44 species, of which 13 are freshwater forms. Of the marine species 3 are arctic, 10 are arctic-subarctic (panarctic), 2 are subarctic, 5 are subarctic-boreal, 2 are typically boreal forms, and 8 are of wide north-to-south range from arctic to boreal. Two of the panarctic species, *Icelus spatula* and *Eumesogrammus praecisus*, are not known east of Greenland or west of the Kara Sea, and are probably of Pacific origin.

Only five of the total number are known to be circumpolar, though several others probably are.

Polychaetes: 74 species. Circumpolar or probably so, 42 species; panarctic, 15; arctic-subarctic-boreal, 49; "cosmopolitan", 9; probably of Pacific origin, not known east of the Canadian Eastern Arctic, 3. (In all, 134 species of polychaetes are now known from the Eastern Arctic, of which 8 belong to this Pacific group).

Echinoderms: 26 species. Circumpolar or probably so, 14; panarctic, 13; arctic-subarctic-boreal, 10; Pacific species known only as far east as Greenland, 2. *Amphipods*: 114 species. Circumpolar or probably so, 45; arctic, 3, perhaps 7; subarctic only, 13; panarctic, 32; panarctic-boreal or subarctic-boreal, 57; recorded also from the Japan Sea or the Sea of Okhotsk, 33; known only from the Atlantic sector, 28, of which 12 belong to the single family Stenothoidae; Pacific forms not known west of the Kara Sea or east of Greenland, 6.

In all four groups there is a certain small proportion of species that are known only from North America and Siberia, but not from the intervening European waters. These are very probably immigrants to both regions (North America and Siberia) from the Pacific by way of Bering Strait. They are thus in the same category as certain species of decapod crustaceans known from the West Greenland coast, and of certain fishes known from Hudson Bay (Vladykov, 1933). It is also interesting that Doutt (1942) found that the freshwater harbour seal (*Phoca vitulina*) from the Seal Lakes of the Ungava Peninsula showed closer affinity to the Pacific than to the Atlantic subspecies.

Plankton production and standing crop

The Ungava Bay copepod plankton (harpacticoids excluded) has been found to contain 22 species, 5 of which had not been previously recorded from the western North Atlantic (Fontaine, 1955). With one exception, the species are all panarctic in distribution; the exception is the boreal form *Pleuromamma robusta*, of which only two specimens are recorded from Ungava Bay. *Calanus finmarchicus* breeds continuously in the short summer, but apparently goes through only one generation per year. The same is true of *Pseudocalanus minutus*, but it is possible that in this species part of the population breeds a second time in the fall. *Ascartia longiremis* and *Oithona similis* spawn in July, probably producing only one generation per year.

The breeding cycles, growth rates, and metabolic rates of cold water holoplanktonic animals are matters of considerable general interest upon which much work has still to be done. Evidence has been brought forward by various workers that growth rates of certain littoral and benthonic species are not lower in cold arctic waters than those of the same or closely related species in temperate and even subtropical waters, and that the same is true of the metabolic rates measured in terms of oxygen consumption. It appears clear, however, that in the holoplanktonic species so far studied, the growth is much slower in cold water. The measurement of the metabolic rates is the next step in this particular line of research, and is planned for the immediate future in the *Calanus* series. For a general review of recent work on metabolic regulation with respect to temperature in poikilotherms see Bullock (1955). The breeding cycle in the large pelagic amphipod *Themisto libellula* is at present under study; its growth is slow, and its life cycle appears to take two years, with only one breeding period per individual. Similar work will shortly be undertaken on the Euphausiacea.

Hudson Bay is intensely stratified in the upper 50 metres in summer, so much so that there has been doubt expressed as to whether a normal vertical exchange during the winter is achieved; until a few years ago it was also thought possible that the water below 50 metres was dynamically dead and therefore might be expected to be very low in oxygen content. As regards the former possibility, hydrographic work has now been carried out in the winter, but the results are not yet available. The oxygen content of the deep water in Hudson Bay is normal, and there is therefore no reason to suspect unusually poor conditions for the production of phytoplankton or zooplankton. The standing crop of zooplankton is not much below that of Ungava Bay, judging from present results; and the phytoplankton, according to Mr. Bursa's work with the plankton (Utermöhl) microscope, maintains a standing crop in summer that is only a little below that of the western end of Hudson Strait, where the stability of the water is much less.

The standing crop of plankton has been sampled by means of (1) the two-metre stramin net hauled horizontally, (2) the Henson net with No. 6 bolting silk hauled vertically, and (3) water samples preserved in weak neutralized formalin for estimation with the Utermöhl microscope. Measurement of the rate of production of organic matter in Hudson Bay is being undertaken at present by means of the oxygen (Winkler) method. The results promise to be very interesting, for they suggest that the method may need considerable modification, and that there may be factors not yet considered, such as the possible dampening of zooplankton activity in the darkened bottle, and even the possibility of a considerable lag in the cessation of synthesis of organic matter in the dark, which complicates the interpretation of the results, and which may apply especially to the use of the method in water of very low temperature.

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[Contribution from the Fisheries Research Board of Canada, Chemistry Section of the Technological Station at Vancouver, B. C.]

Marine Sterols. III. The Synthesis of 24-Methylenecholesterol and 25-Dehydrocholesterol

By D. R. Idler and U. H. M. Fagerlund

Received October 22, 1956

A new sterol, 24-methylenecholesterol, recently isolated from several molluscs, has been synthesized from 24-ketocholesterol employing triphenylphosphinemethylene. The synthesis of 25-dehydrocholesterol is also reported and discrepancies in its properties with the products previously assigned this structure are discussed. Evidence is presented to support the conclusion that the earlier preparations are not 25-dehydrocholesterol and it is suggested that they are the previously undescribed 24-dehydrocholesterol. The broader implications of the use of triphenylphosphine alkylidene compounds in syntheses in the sterol side chain are outlined.

A new sterol, 24-methylenecholesterol, has recently been isolated from several species of shellfish.[1,2] The structure was established by chemical degradation and the present study was undertaken to confirm this structure by synthesis. Further, it was suggested that the biological reduction of 24-methylenecholesterol offered a possible explanation for the origin of C_{24}-epimeric 28-carbon sterols in nature and by a similar route fucosterol (24-ethylenecholesterol), isolated from algae,[3,4] would explain the origin of C_{24}-epimeric 29-carbon sterols. In our planned approach to test the validity of this hypothesis it will be necessary to have a source of 24-methylenecholesterol and fucosterol labeled with C^{14} in the alkylidene group.

Syntheses of side chain double bonds have been accomplished in a few instances by the use of dehydrohalogenation reactions. Thus, a compound assigned the structure 25-dehydrocholesteryl acetate has been prepared from 25-hydroxycholesteryl acetate in good yield with $POCl_3$ and pyridine, but the same reaction conditions employing 26-nor-5-

(1) D. R. Idler and U. H. M. Fagerlund, This Journal, **77**, 4142 (1955).

(2) U. H. M. Fagerlund and D. R. Idler, *J. Org. Chem.*, **21**, 372 (1956).

(3) I. M. Heilbron, R. F. Phipers and H. R. Wright, *Nature*, **133**, 419 (1934); *J. Chem. Soc.*, 1572 (1934).

(4) H. B. MacPhillamy, This Journal, **64**, 1732 (1942).

cholestene-3,25-diol-3-acetate gave the 25-chloro derivative.[5–7] The conversion of cholestane-3,22-diol-3-acetate to 20(22)-cholestenyl acetate, apparently in reasonable yield, has been reported.[8]

Syntheses in the side chain have been made possible primarily by the availability of ketones such as 22- and 24-ketocholesterol and 25-ketonorcholesterol prepared from readily available intermediates.[9–11] Because of the sometimes numerous and closely related possible products from dehydrohalogenation reactions, a more direct method of introducing double bonds, but preferably still employing the ketone starting materials, was sought. The recently discovered elegant triphenylphosphine alkylidene reagent of Wittig and Schöllkopf, which permits the direct replacement of a ketone by an alkylidene group, appeared to be such a reagent.[12,13] This reagent has already been used to a limited extent, notably in the synthesis of squalene[14] and precursors to be used for the synthesis of vitamin D type compounds.[15–17]

The present paper reports the successful synthesis of 24-methylenecholesterol (II) from 24-ketocholesterol (I) and shows its identity with the natural product. In addition, 25-dehydrocholesterol has been prepared and discrepancies in properties with previously described products discussed. Other applications of the reaction to sterol syntheses are outlined briefly.

Experimental[18]

Methyltriphenylphosphonium Bromide.—To 50 ml. of benzene at 0° were added 20 g. of triphenylphosphine and 10 g. of methyl bromide. After standing for one day at

(5) A. I. Ryer, W. H. Gebert and N. M. Murrill, *ibid.*, **72**, 4247 (1950); **75**, 491 (1953).

(6) A. I. Ryer and W. H. Gebert, U. S. Patent 2,673,206 (1954).

(7) W. G. Dauben and H. Leon Bradlow, This Journal, **72**, 4248 (1950).

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(10) B. Riegel and I. A. Kaye, This Journal, **66**, 723 (1944).

(11) W. Cole and P. L. Julian, *ibid.*, **67**, 1369 (1945).

(12) G. Wittig and U. Schöllkopf, *Chem. Ber.*, **87**, 1318 (1954).

(13) The selection of this reaction resulted from discussions of D.R.I. with Dr. G. Tener and Dr. J. G. Moffatt of the British Columbia Research Council.

(14) S. Trippett, *Chemistry & Industry*, 80 (1956).

(15) N. A. Milas, Li-chin Chiang, C. P. Priesing, A. A. Hyatt and J. Peters, This Journal, **77**, 4180 (1955).

(16) I. T. Harrison, B. Lythgoe and S. Trippett, *Chemistry & Industry*, 507 (1955).

(17) H. H. Inhoffen, K. Bruckner, G. F. Domagk and H. M. Erdmann, *Chem. Ber.*, **88**, 1415 (1955).

(18) Melting points are uncorrected except for 25-dehydrocholesterol and derivatives. Optical rotations were measured by means of a Rudolph precision polarimeter with a photoelectric attachment. Rotations also were checked visually. Infrared spectra were recorded with a Perkin–Elmer recording infrared spectrophotometer.

room temperature in a pressure bottle, the methyltriphenylphosphonium bromide was filtered off and washed with benzene (13.3 g., m.p. 227–228°).

Triphenylphosphine Methylene Reagent.—Methyltriphenylphosphonium bromide (2.45 g.), phenyllithium (7.5 ml. of an ether solution titrating 9.5 ml. of 0.1 *N* HCl per ml. and prepared from 1.4 g. of lithium and 15.7 g. of bromobenzene in 50 ml. of ether in the usual manner) and 19 ml. of ether, were shaken in a pressure bottle for 3 hr. at 20°.

24-Ketocholesteryl Acetate.—Diisopropylcadmium was treated with 3-acetoxy-5-cholenyl chloride (prepared as previously described)[19,20] according to the procedure of Riegel and Kaye.[10] (For our early experiments 3-acetoxy-5-cholenyl chloride and 24-ketocholesteryl acetate were gifts of other workers.) The product was purified by chromatography on silicic acid,[1] m.p. 128°, $[\alpha]^{22}D$ −43°, mixed m.p. 128° with the ozonolysis product from 24-methylenecholesterol.

Anal. Calcd. for $C_{29}H_{46}O_3$: C, 76.68; H, 10.48. Found: C, 76.59; H, 10.40.

24-Methylenecholesterol.—24-Ketocholesteryl acetate (225 mg.) and triphenylphosphinemethylene reagent (15 ml.) were shaken in a pressure bottle for 1 hr. at room temperature followed by 5 hr. at 65°. The precipitate was filtered and washed with anhydrous ether. The filtrate was evaporated to dryness, reacetylated and taken up in 20 ml. of Skellysolve C and the steryl acetate adsorbed on a column (7.5 cm. o.d. × 8 cm.) of silicic acid–Celite 2:1.[1] The adsorbent was washed with 400 ml. of Skellysolve C and the eluate discarded. The steryl acetate broke through with 300 ml. of benzene–Skellysolve C 1:1 and a further 400 ml. completed the elution. 24-Methylenecholesterol (140 mg.), prepared by hydrolyzing the acetate, melted at 143°, $[\alpha]^{22}D$ −34.8° (26 mg. in 1 ml. of $CHCl_3$), (N.P.[21] m.p. 142°, $[\alpha]^{22}D$ −35.0°) mixed m.p. with N.P. 143°. The infrared spectrum was identical with the natural product and had the prominent absorption bands at 1637 and 885 $cm.^{-1}$ associated with a terminal methylene group[1] (Fig. 1).

A further 20 mg. of sterol, m.p. 140°, was obtained with digitonin from the supernatant. The total yield was 160 mg. (70%).

Anal. Calcd. for $C_{28}H_{46}O$: C, 84.35; H, 11.63. Found: C, 84.41; H, 11.60.

Derivatives.—The acetate crystallized from ethanol in plates, m.p. 135°, $[\alpha]^{22}D$ −44.1° (28.5 mg. in 1 ml. of $CHCl_3$), (N.P. m.p. 136°, $[\alpha]^{22}D$ −42.4°) mixed m.p. with N.P. 136°.

Anal. Calcd. for $C_{30}H_{48}O_2$: C, 81.76; H, 10.98. Found: C, 81.64; H, 10.88.

The benzoate was prepared in the usual manner and crystallized from acetone in plates, m.p. 148°, $[\alpha]^{22}D$ −14.0° (N.P. m.p. 148°, clear 153°), $[\alpha]^{22}D$ −14.1°, mixed m.p. with N.P. 148°.

25-Dehydrocholesterol.—The triphenylphosphinemethylene reagent (15 ml.) was treated with 225 mg. of 25-ketonorcholesteryl acetate and after reacetylation the steryl acetate isolated by chromatography as described above for the 24-methylene compound. Hydrolysis, followed by crystallization from methanol gave fine needles, m.p. 132.5°, $[\alpha]^{22}D$ −40.7° (20.2 mg. in 1 ml. of $CHCl_3$) (lit. 121.2–

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(20) S. Kuwada and M. Yogo, *J. Pharm. Soc.* (*Japan*), **57**, 963 (1937).

(21) The natural product (N.P.) obtained from molluscs.[1,2].

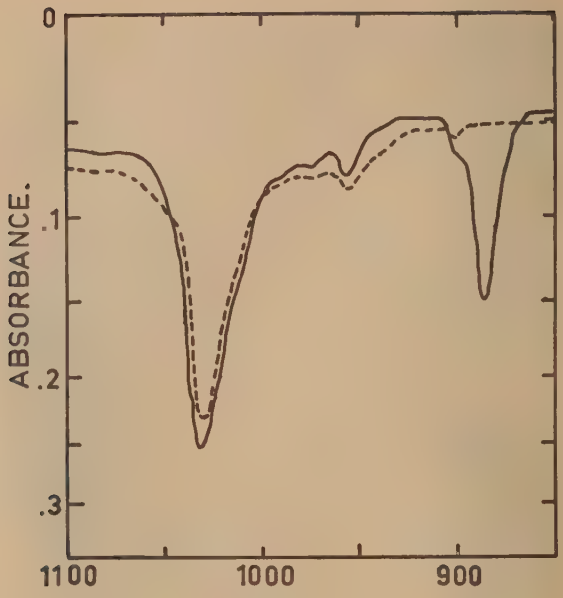


Fig. 1.—Infrared spectra of 25-dehydrocholesteryl acetate — and an earlier preparation[5] – – –. Spectra were determined in carbon tetrachloride.

122.2°, $[\alpha]^{22.5}D$ −43.0°,[5] and 120.5–121.5°, $[\alpha]^{25}D$ −40.2°[7]). The yield was 120 mg. (53%).

Anal. Calcd. for $C_{27}H_{44}O$: C, 84.31; H, 11.53. Found: C, 84.23; H, 11.42.

Derivatives.—The acetate crystallized from methanol in plates, m.p. 112°, $[\alpha]^{22}D$ −44.4° (32 mg. in 1 ml. of $CHCl_3$) (lit. 93.5–94°, $[\alpha]^{29}D$ −43.6°,[5] and 92.5–93.5°, $[\alpha]^{22}D$ −42.8°[7]).

Anal. Calcd. for $C_{29}H_{46}O_2$: C, 81.63; H, 10.87. Found: C, 81.60; H, 10.72.

The benzoate was prepared by dissolving 35 mg. of the sterol in 1 ml. of pyridine and 0.2 ml. of benzoyl chloride, followed by incubation at 37° overnight. The steryl benzoate was precipitated with 90% ethanol and crystallized twice from aqueous acetone in clusters of fine needles, m.p. 126°, $[\alpha]^{22}D$ −16.7° (21 mg. in 1 ml. of $CHCl_3$); molecular rotational differences: 25-dehydrocholesterol, Δ^{Ac} −24, Δ^{Bz} +84; cholesterol, Δ^{Ac} −51, Δ^{Bz} +84.

It is thus apparent that the contribution to molecular rotation differences of the 25-double bond is significant for the acetate but not for the benzoate.

Periodate Oxidation.—Formaldehyde was determined by the periodic acid–permanganate procedure of Bricker and Roberts slightly modified to allow for the limited solubility of steryl acetates in aqueous ethanol.[22] The modification simply involved the use of 6 ml. of alcohol in place of 3 ml. as described in the original procedure. Employing 24-methylenecholesteryl acetate as a standard our preparation of 25-dehydrocholesteryl acetate gave 98% of the theoretical

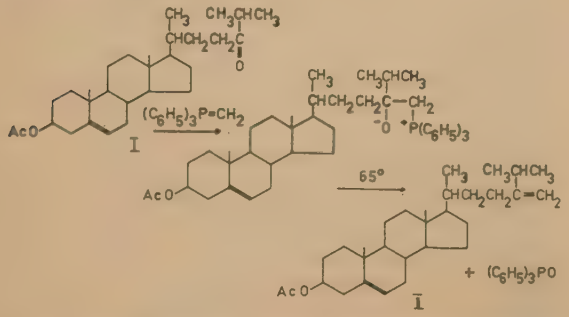
(22) C. E. Bricker and K. H. Roberts, *Anal. Chem.*, **21**, 1297 (1949).

weight of formaldehyde. By comparison the earlier preparations[5,6] gave 99 and 100%, respectively. Hence, within the limits of the method all preparations gave the yield of formaldehyde expected from one terminal methylene group.

The cleavage also was carried out by the same procedure except that basic $KMnO_4$ was added first followed by periodic acid. Acetone was then determined by both the nitroprusside reaction and conversion to indigo with O-nitrobenzaldehyde.[23] Both earlier preparations of 25-dehydrocholesteryl acetate gave positive tests for acetone.

Discussion

Syntheses of the type described in this paper provide a route to steroids C^{14}-labeled in specific positions in the side chain from readily available intermediates. Conditions found suitable for obtaining an adequate yield of 24-methylenecholesterol were used without modification for the preparation of 25-dehydrocholesterol. A Grignard reaction previously has been employed to synthesize 7-methylenecholesterol from 7-ketocholesterol.[24] In our hands 7-ketocholesterol aecteta was converted to 7-methylenecholesteryl acetate with triphenylphosphinemethylene as described above for 24-methylenecholesterol but the yield was not investigated. It is obvious that this reaction suggests a route to many interesting sterols, including the still undescribed 17(20)- and 20(21)-unsaturated derivatives in the cholesterol series. For example, 5,17(20)-cholestadiene-3β-ol would be prepared from dehydroandrosterone and 2-bromo-6-methylheptane, both fairly readily available. Interest in these compounds is also centered around determining the contribution of the remaining isolated side chain double bonds to infrared spectra, optical rotation and the color reactions of sterols. We hope to make some of these syntheses the subject of a future report.



A sterol assigned the 25-dehydrocholesterol structure previously has been synthesized concur-

(23) F. Feigl, "Qualitative Analysis by Spot Tests," Elsevier Publ. Co., Inc., New York, N. Y., 1947, p. 351.

(24) B. Bann, I. M. Heilbron and F. S. Spring, *J. Chem. Soc.*, 1274 (1936).

rently in two laboratories by a dehydrohalogenation reaction, and the properties of the sterol and its derivatives differ significantly from those reported here (Table I).[5–6] The dehydrohalogenation of 25-chlorocholesterol would have to proceed nearly quantitatively in the unexpected manner in order to obtain pure 25-dehydrocholesterol, and for this reason we first believed that the products were contaminated with the 24-unsaturated isomer.

TABLE I

PROPERTIES OF 25-DEHYDROCHOLESTEROL AND EARLIER PREPARATIONS

	Idler and Fagerlund		Ryer, *et al.*[5]		Dauben, *et al.*[7]	
	M.p., °C.	α_D	M.p., °C.	α_D	M.p., °C.	α_D
Sterol	133	−40.7°	121.2–122.2	−43.0°	120.5–121.5	−40.2°
Acetate	112	−44.4	93.5–94	−43.6	92.5–93.5	−42.8
Benzoate	126	−16.7	.....		.....	
Yield of CH_2O, %	98		99		100	
Infrared adsorption at 885 and 1637 cm.$^{-1}$	Yes		No		No	

The results of periodate oxidation indicate that the earlier preparations do yield the theoretical amount of formaldehyde as compared with the product prepared from triphenylphosphinemethylene (Table I). However, mixture melting points of our 25-dehydrocholesteryl acetate (m.p. 118°) in both cases depressed the melting point (92.5–93.5° and 92.5–94°[6,7]) of the earlier preparations. This contradicted the conclusion that the previous preparations were 25-dehydrocholesteryl acetate contaminated with 24-dehydrocholesteryl acetate, for if this were the case the further addition of 25-dehydrocholesteryl acetate should have raised the melting point. Infrared spectra were run on all three preparations and there was no evidence for any significant absorption at 885 cm.$^{-1}$ characteristic of terminal unsaturation in the earlier preparations. The absorption at 1637 cm.$^{-1}$ for terminal unsaturation found in our preparation of 25-dehydrocholesterol (Fig. 1) and 24-methylenecholesterol was also absent.[1,25,26] We must conclude that the earlier products are not 25-dehydrocholesterol but are predominately the previously undescribed 24-dehydrocholesterol arising by dehydrohalogenation proceeding in the expected manner. The incorrect assignment of structure by the earlier workers may be explained by the apparent non-specificity of the formaldehyde determination when applied to sterols of this type;

(25) R. B. Barnes, R. C. Gore, R. W. Stafford and V. Z. Williams, *Anal. Chem.*, **20**, 402 (1948).

(26) H. W. Thompson and D. H. Whiffen, *J. Chem. Soc.*, 1412 (1948).

bond migration under the acid conditions of the periodate oxidation might offer an explanation. The formation of acetone when basic permanganate was used lends support to this hypothesis.

Acknowledgment.—We are indebted to Dr. Byron Riegel, G. D. Searle and Co., Chicago, Ill., for a sample of synthetic 24-ketocholesterol; to Drs. Eugene P. Oliveto and W. Gebert, Schering Corp., Bloomfield, N. J., for synthetic 25-ketonorcholesterol and 25-dehydrocholesterol; to Dr. H. B. MacPhillamy, Ciba Pharmaceutical Products, Inc., Summit, N. J., for 3-acetoxy-5-cholenic acid; and to Dr. W. G. Dauben, University of California, for 25-dehydrocholesterol. Dr. R. H. Wright, British Columbia Research Council, kindly recorded infrared spectra. Mr. A. P. Ronald of our instrumentation section obtained many of the analytical data.

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TRANSACTIONS OF THE ROYAL SOCIETY OF CANADA
VOLUME L : SERIES III : JUNE, 1956
CANADIAN COMMITTEE ON OCEANOGRAPHY

Oceanographic Features of Submarine Topography

H. B. HACHEY, F.R.S.C., L. LAUZIER and W. P. BAILEY

Introduction

ONE phase of oceanography, the study of the sea floor, is of practical as well as fundamental interest. The practical interest is generally related to the shallower areas, where a knowledge of depths, and of the general configuration of the bottom, is important for maritime shipping, the location of cables, a fishery or problems of national defence. In recent years there has been a growing interest in deep sea oceanography. The study of bottom deposits by seismographic methods is permitting the reconstruction of oceanographic topography of previous geological periods. The analysis of sediments, involving geological, chemical, and biological methods, is furnishing information on the climatic variations during glacial and post-glacial periods.

The present paper is concerned with some oceanographic features of submarine topography with particular reference to the sea floor around Canada, and deals specifically with North Atlantic and Arctic areas.

Submarine Ridges and Basins

In the North Atlantic Ocean (Johnstone, 1923, p. 51), one of the major features of the submarine topography is the North Atlantic Ridge with depths between 2,000 and 4,000 metres, extending from the south of Greenland to the equatorial regions, thence into the South Atlantic where it is known as the South Atlantic Ridge. In the North Atlantic this ridge separates the North American Basin from the Cape Verde Basin.

A second feature of the submarine topography of the North Atlantic is the extended nature of the continental shelf. Within the general area of this shelf, which extends all the way across the North Atlantic, are shallow inland seas such as Hudson Bay and the Baltic, and deep inland seas such as the Caribbean, the Gulf of Mexico, and the Mediterranean.

A third feature is the expansion of the North Atlantic Ridge to the north into what is known as the Telegraph Plateau, which in turn merges into the continental shelf to the north.

The various areas of ocean waters delineated by the general submarine topography, thus briefly outlined on the grand scale, have their own specific oceanographic features which are receiving increasing attention from students of deep sea oceanography. The great contrasts in water conditions between the open Atlantic and the Norwegian Sea, due to the existence of

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the Wyville-Thomson Ridge (Johnstone, 1923, p. 267), with depths of 400–500 metres, is the classic example of the effect of a submarine ridge in preventing full interchange of ocean waters. To the west, in the North Atlantic (Hachey *et al.*, 1954, Fig. 2), the northward extension of the North American Basin between Greenland and Labrador, and the persistence of depths greater than 1,000 metres towards Davis Strait, have a profound influence on the water exchanges between the Arctic and the Atlantic. This is demonstrated by the unique southerly flow of Arctic water, ice, and icebergs, extending even south of latitude 45°N.

Submarine barriers, whether large or small, form the boundaries of submarine basins in which horizontal communication with adjacent seas is restricted by sill depth. Renewals of the water in the basin can take place only through processes of vertical circulation; and it is therefore characteristic of all basins that, below sill depth, the water is nearly uniform in temperature and salinity, and approximately of the same character as the waters at the sill depth.

Submarine Valleys

The many furrows cutting across the continental shelf, some areas of which have received considerable attention in recent years, are generally referred to as canyons. Some of these canyons can be traced across the shelf, and even into the estuaries of rivers. Various theories have been put forward to explain the formation of such submarine canyons, but no single hypothesis has yet been advanced to account for their characteristic features (Shepard and Emery, 1941).

Separating the Grand Banks from the Scotian Shelf is the submerged Laurentian Channel or Trough, with depths from 200 to 600 metres; it extends into the Gulf of St. Lawrence, thence into the St. Lawrence estuary as far as the mouth of the Saguenay River (Hachey *et al.*, 1954, Fig. 3). Geologists tell us that in pre-glacial times, eastern Canada extended to the edge of the continental shelf, 140 miles beyond the present southwestern coast of Nova Scotia, and Newfoundland was a part of the mainland. The ancient St. Lawrence River channel can be followed by soundings to the edge of the enlarged continent, where the bottom descends to the depths of the sea (Coleman, 1922). Students of continental faulting have been attempting to trace the faults of Cape Breton across Cabot Strait to Newfoundland, and have suggested that the Laurentian Channel is, in part, of the nature of a "fault graben" (Gregory, 1929). Shepard (1931) made a thorough study of the various charts of the Laurentian Channel, combined with a special investigation of Cabot Strait. From this study he concluded that the St. Lawrence trough probably was started by river erosion, possibly, in part, along the fault lines. Later during the glacial period, tongues of ice moved down the valley causing great deepening and widening. The present form of the trough is believed to be due principally to this glaciation, which makes it a submarine glacial trough. In any event, this deep sub-

merged Laurentian Channel, reaching well into the estuary of the St. Lawrence, not only permits the continental penetration by the deeper waters of oceanic origin, but furthers the phenomenon of the Gaspé Current (Tremblay and Lauzier, 1940).

The Gaspé Current

The Gaspé Current is the result of mixing in an estuary, and its elementary features were outlined by Huntsman (1923), who based his account on the observations made by Bayfield (1837). The phenomenon is unique in that there is a comparatively extreme contrast in the characteristic waters carried into the mixing area. This is shown in Figures 1 and 2 which illustrate the distribution of temperature and salinity in a longitudinal section

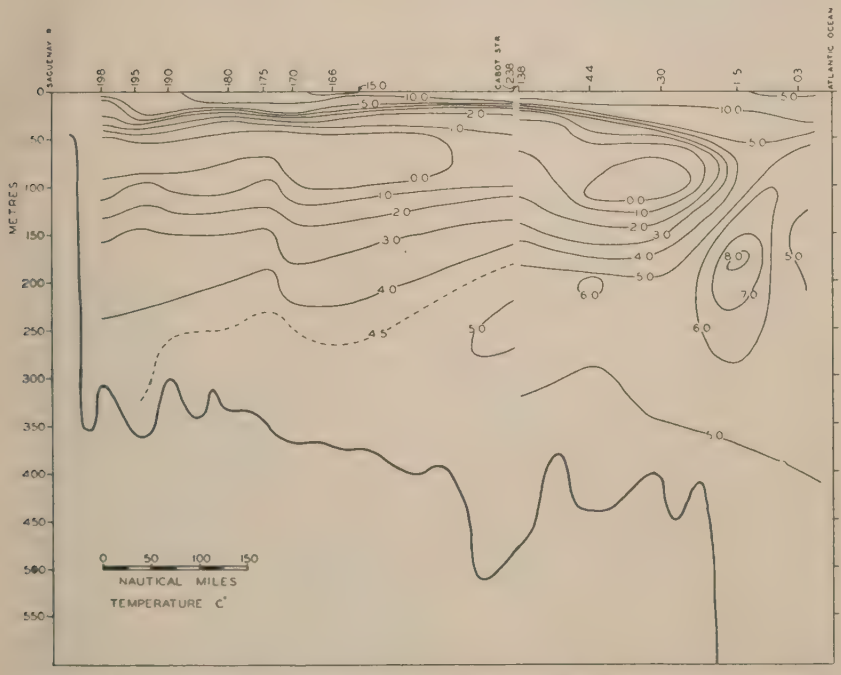

Figure 1.—Distribution of temperature in section along the Laurentian Channel.

extending from the edge of the continental shelf to the region of the Saguenay River.

It will be noted that depths of more than 300 metres extend to the region of the Saguenay, and salinities of greater than 34.5 ‰ extend into the estuary at these depths. A large area of the section between stations 138 and 198 is occupied by waters of salinities less than 32.0 ‰, while two areas in the vicinity of stations 195 and 170 indicate considerable dilution

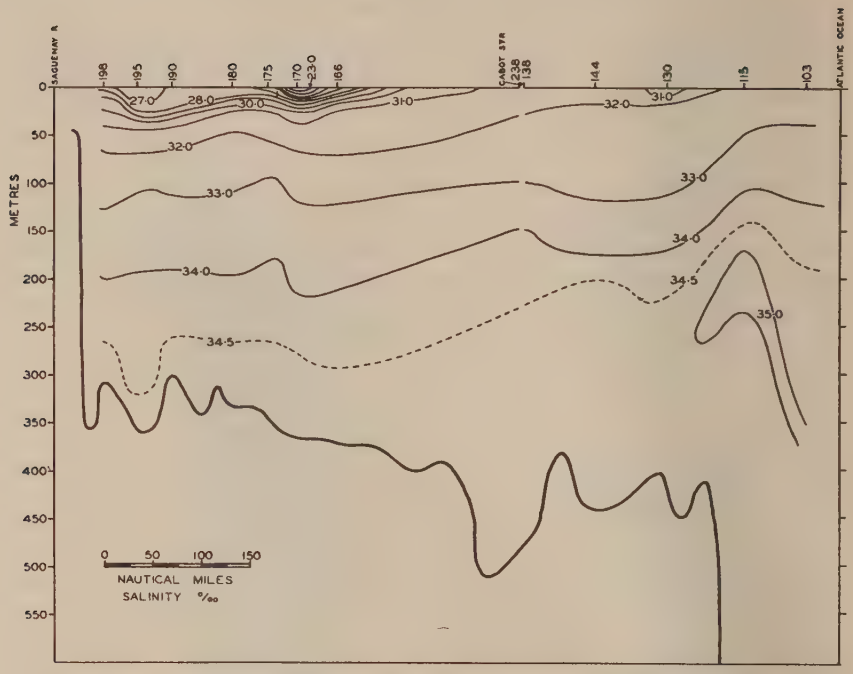

FIGURE 2.—Distribution of salinity in section along the Laurentian Channel.

with land drainage waters. The distribution of temperature in section illustrates the three-layered nature of the waters of the estuary in the summer months: a comparatively warm surface layer, an intermediate cold layer, and a warm bottom layer. The upwelling of deeper and colder waters is much in evidence between stations 190 and 198.

The configuration of the floor of the estuary is shown on Figure 3. On the northern side of the estuary, between the Saguenay and Cap Bon-Désir, a distance of ten miles, the depth decreases from approximately 340 metres to less than 50. The southern side of this area is comparatively shallow, the depths decreasing rapidly from 350 to less than 100 metres to form a gradually sloping shelf of approximately ten miles in width.

The distribution of temperature and salinity in a vertical section covering this area of the estuary, at high and low water, is shown in Figure 4. The locations of the stations of the section are indicated in Figure 3. It will be noted that salinities of 33.0 ‰ and greater, and temperatures as low as –0.6°C. are available to any vertical mixing process in this area. The lowered salinities found in the upper fifty metres of this section at low tide are the result of the mixing of river water with the saline water brought to the mixing area. The production area, and the outward flow of the mixed waters, are indicated in Figure 5. Here are illustrated the distribution of salinities at 10 metres at various stages of the tide. The direction and magni-

FIGURE 3.—Bottom configuration, St. Lawrence estuary.

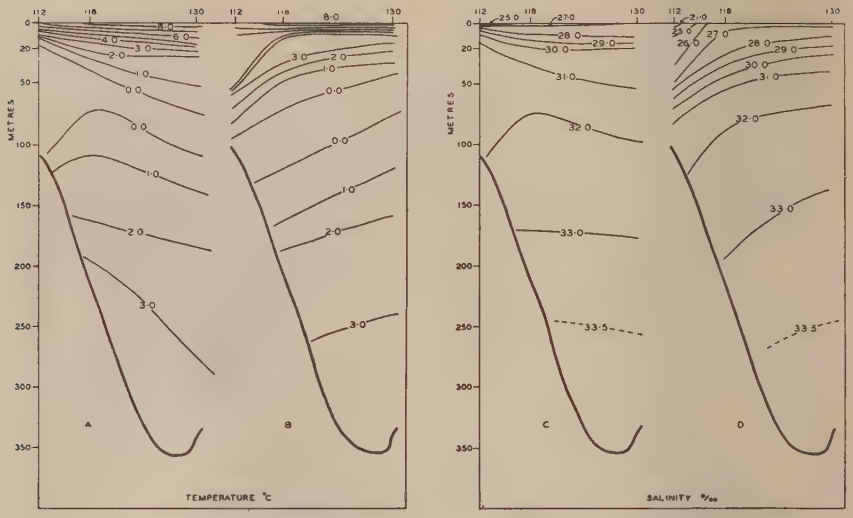

FIGURE 4.—Temperature and salinity in section, St. Lawrence estuary. High water—A and C: Low water—B and D.

tude of the surface currents are indicated by arrows (Department of Mines and Resources, 1939).

It will be noted that the outward flow of the less saline mixed water is directed along the south side of the St. Lawrence River, and this is the result of the Coriolis force. The production of typical waters of the Gaspé Current is further assisted by mixing in the lower reaches of the estuary, particularly in the area above and below Pointe des Monts. Here, too, the current receives further energy through the prevailing dynamical processes. This phase is presently under critical study.

It is thus shown that the Gaspé Current of lowered salinities originates in the upper reaches of the St. Lawrence estuary, and that the following factors enter into the phenomenon: (*a*) the sloping nature of the sea floor in the upper reaches of the estuary; (*b*) the persisting depths of the Laurentian Channel; (*c*) the resultant upwelling and vertical mixing; and (*d*) the concentration of the outward flow along the south shore of the St. Lawrence, the result of the Coriolis force.

THE SEA FLOOR IN THE CANADIAN ARCTIC

The general features of the submarine physiography of the Canadian Arctic and neighbouring seas (Fig. 6) are the basins of the Arctic and of Baffin Bay, the relative shallows of the archipelago and Davis Strait, and the Lomonosov Range which, north of Greenland, divides the Arctic Basin into the eastern and western parts.

The western Arctic Basin has, for the most part, depths greater than 3,000 metres, with one depression near the pole exceeding 4,000 metres in depth.

FIGURE 5.—Salinity at ten metres at various stages of the tide.

Separating the Arctic Ocean from the Atlantic Ocean, the archipelago is interlaced with many relatively deep channels. However, it forms a barrier with an effective sill depth of 200 metres or less between the two basins. The principal channels which connect Baffin Bay to the Arctic Ocean are Smith Sound Kennedy Channel on the north, and Lancaster Sound -Barrow Strait

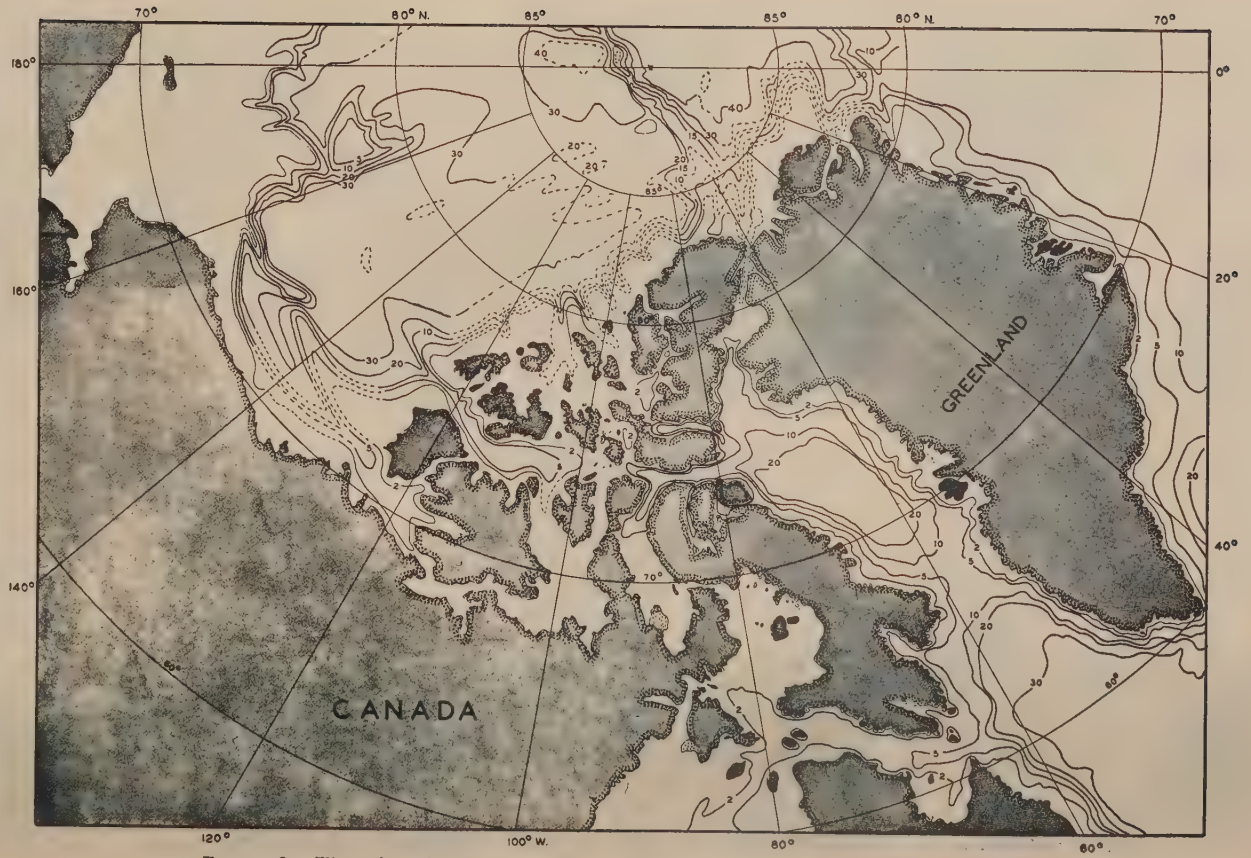

FIGURE 6.—The submarine physiography of the Canadian Arctic and neighbouring seas.

FIGURE 7.—The general circulation in the Canadian Arctic and neighbouring seas.

on the west. The sill depths in these channels are 200 and 175 metres respectively, and depths are of importance here in determining the nature of the water masses in Baffin Bay.

On the eastern side of the archipelago, the channels are deep and lead directly into the basin of Baffin Bay which has depths in excess of 2,000 metres. Baffin Bay is in turn separated from the Atlantic Ocean by a sill in Davis Strait with a depth of 700 metres. To the south of Davis Strait, depths gradually increase to those of the Labrador Basin.

General Circulation

The general circulation of the waters of the Canadian Arctic and neighbouring seas, as shown in Figure 7, is a composite picture obtained from a variety of general studies of circulation in these areas. It will be noted that there is a tendency for easterly and southerly flow from the Arctic Ocean to the Atlantic Ocean, and for a counter-clockwise circulation in the Labrador Basin–Baffin Bay area. The main outflow from the Arctic to the Atlantic takes place on the eastern side of Greenland in the form of the East Greenland Current. This current, in rounding the southern tip of Greenland, is joined by the Irminger Current to form the West Greenland Current which flows northward along the west coast of Greenland. On reaching Davis Strait, this current divides, one branch continuing its northward course, while the other swings westward to join the southward flowing Baffin Land Current and thus form the Labrador Current. The northward extension of the West Greenland Current joins the waters flowing southward from the Arctic Ocean through Smith, Jones, and Lancaster Sounds to form the Baffin Land Current.

Vertical Distribution of Temperature and Salinity

Arctic Ocean to Labrador Sea

The vertical distribution of temperature and salinity in a section extending from a point near the north pole to the Labrador Sea is illustrated in Figures 8 and 9. In the Labrador Sea, the summer temperatures gradually decrease from the surface to the bottom and are generally warmer than 3.0°C. Summer salinities range from approximately 34.0 ‰ on the surface to approximately 35.0 ‰ at the greater depth. In Baffin Bay, except for the immediate surface, temperatures increase with depth from less than –1.5°C. to approximately 0.0°C. Salinities increase from less than 33.5 ‰ on the surface to approximately 34.5 ‰. In Kane Basin, and to the north, temperatures increase from less than –1.5°C. on the surface to 0.0°C. at depths of 700 metres and then decrease to values of approximately –0.8°C. In the Arctic Ocean, a layer of water of temperatures greater than 0.0°C. at depths between 200 and 700 metres is interposed between a surface layer of temperatures as low as –1.5°C. and a

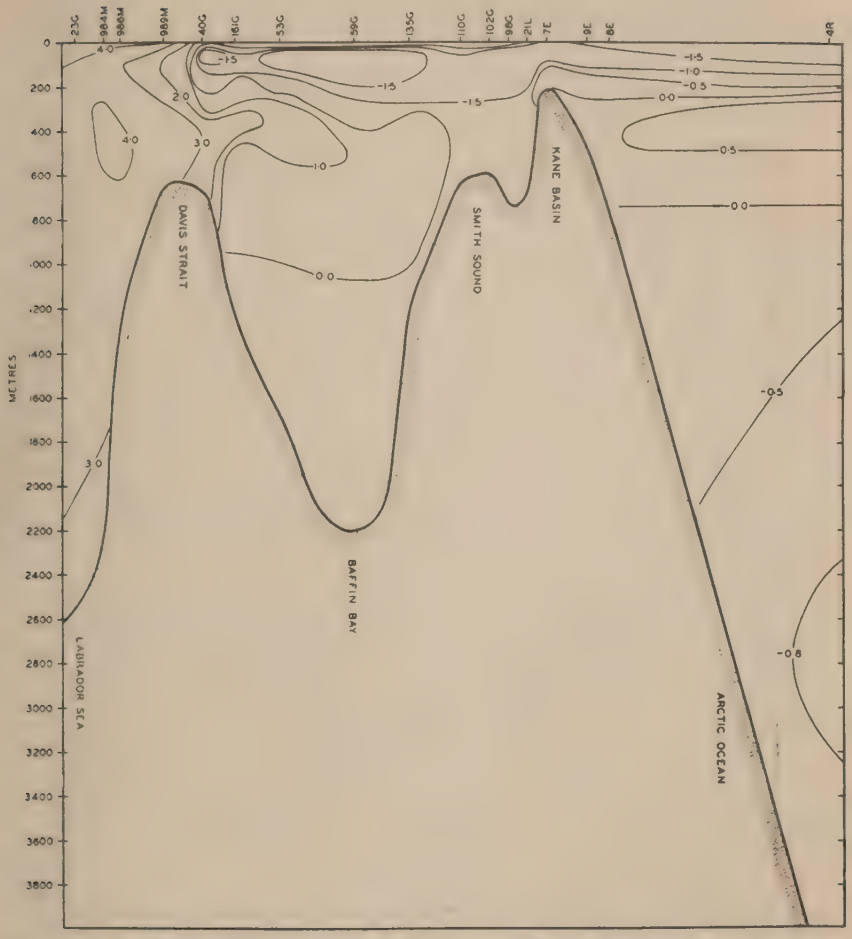

FIGURE 8.—The vertical distribution of temperature: Arctic Ocean to Labrador Sea.

deeper layer where temperatures are as low as –0.8°C. Salinities are of the order of 34.5 ‰ at 200 metres.

It is quite evident that the threshold of Davis Strait is a deterrent to the extensive penetration of waters from the Labrador Sea into Baffin Bay. That some does occur above the threshold is indicated by the distribution of both salinity and temperature. The surface layer of Baffin Bay has the characteristics of waters of the Arctic Ocean, and the threshold of Kane Basin prevents the southerly movement of the deeper waters. Bailey (1956) has shown that the deep water in Baffin Bay originated in the Arctic Ocean. The process probably involves a progressive southerly movement at depths less than 250 metres of Arctic Ocean water which is denser than the main water body of Baffin Bay. It would seem however that the replenishment

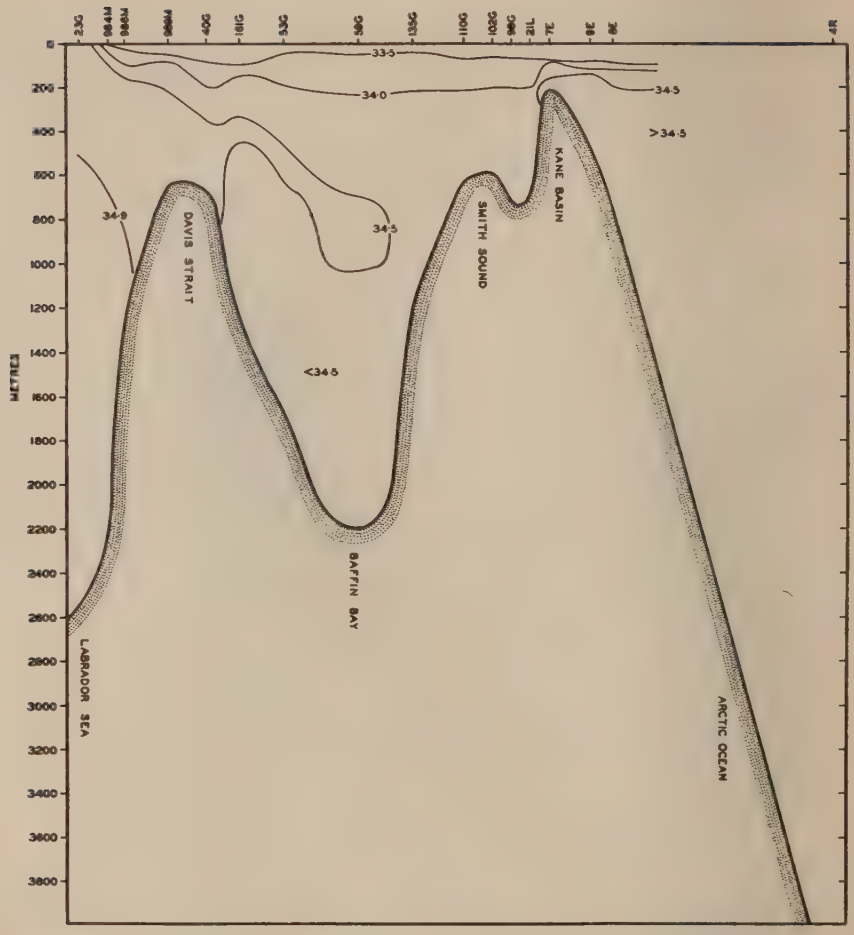

FIGURE 9.—The vertical distribution of salinity: Arctic Ocean to Labrador Sea.

of this deep water in Baffin Bay is at a very slow rate as oxygen depletion from 7.6 ml/l at the surface to 3.5 ml/l at a depth of 2,000 metres has been observed (Riis-Carstensen, 1936). The dominant factors determining the specific characteristics of the water mass in Baffin Bay appear to be the sub-surface horizontal and vertical circulation, confined to the Bay by the configuration of the bottom.

Beaufort Sea to Baffin Bay

The vertical distribution of temperature and salinity in a section from the Beaufort Sea to Baffin Bay is indicated in Figures 10 and 11. Various narrow and shallow passages in the archipelago prevent the free interchange of waters at depths much below 250 metres. We find that the surface layer in

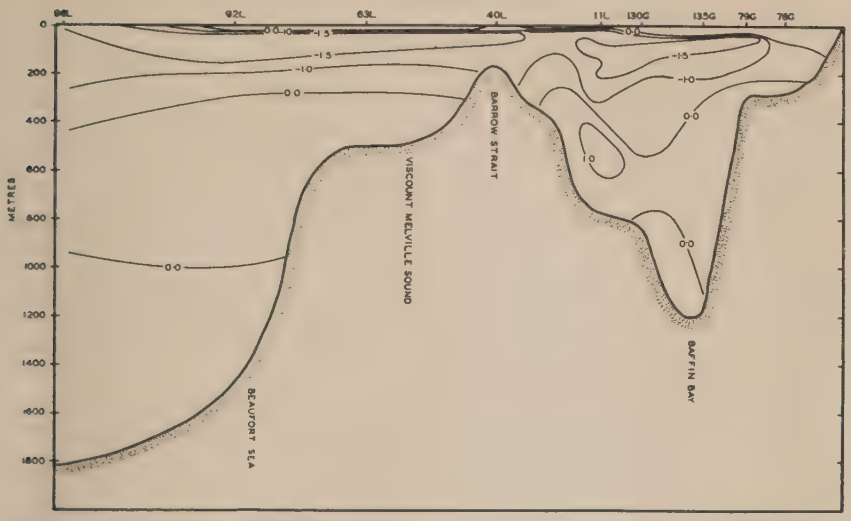

FIGURE 10.—The vertical distribution of temperature: Beaufort Sea to Baffin Bay.

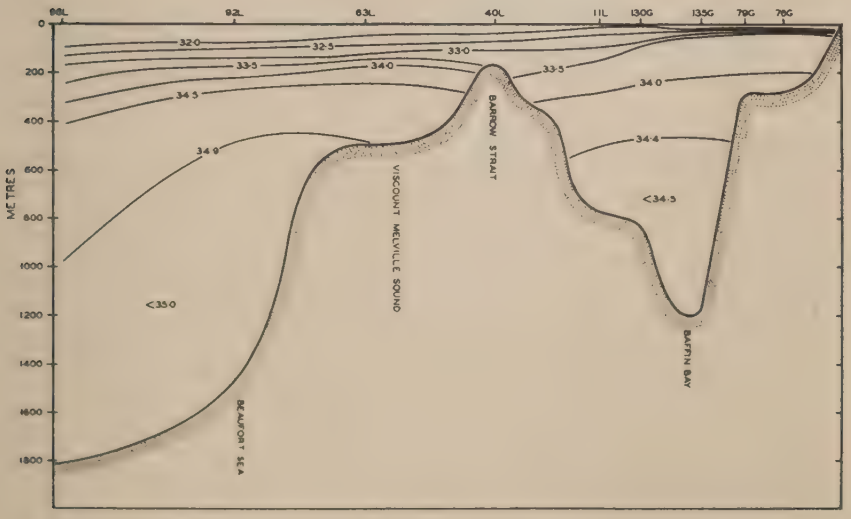

FIGURE 11.—The vertical distribution of salinity: Beaufort Sea to Baffin Bay.

the Beaufort Sea is fresher than that of Baffin Bay. The temperatures at all depths are quite similar, but at depths greater than 250 metres, the waters of the Beaufort Sea are more saline that those of Baffin Bay. It has already been shown that the comparatively low salinities at considerable depth in Baffin Bay are due to the lack of exchange with both the deeper waters of the Arctic Ocean and the Labrador Sea.

Discussion

It has been shown that the Laurentian Channel is an important feature in the phenomenon of the Gaspé Current. This deep channel, penetrating the continental shelf and extending into the estuary of the St. Lawrence River, brings deep ocean waters to the mixing areas of the estuary. The flow of the Gaspé Current is thus initiated by the dynamics of the system and nurtured by the amount and density of the mixed water produced. Were it not for this mechanism, the flow from the St. Lawrence, involving the drainage of half a continent, would be similar to that of most estuaries, wherein the fresh water is gradually dispersed, mixing only with surface waters as it proceeds oceanward.

The effectiveness of submarine ridges in preventing full exchange of waters in the Canadian Arctic and bordering seas has been illustrated. The bottom configuration in the Arctic to the north of the American continent and the nature of the land masses prevent free exchange of the deeper waters. The result is emphasized in features of the southward flow of the Labrador Current, and in the extension of the Arctic ice and climate well to the south on the east coast of North America.

The geology of the sea floor is associated with many problems of physical, chemical, and biological oceanography. One phase of marine geology is concerned with the topographic features of the sea floor. The intimate connection between submarine geomorphology and problems in physical oceanography has been illustrated herein.

The subject is almost inexhaustible, and in some cases a localized submarine topographic feature may have ocean-wide implications. Much has been written of the Gulf Stream system, the primary circulation of the North Atlantic. The energy imparted to the waters by the wind system of equatorial regions is concentrated in part, and conserved in the Gulf Stream. The course of the Gulf Stream between the Straits of Florida and the Grand Banks, and the conservation of energy within a narrow band of considerable depth, is aided and abetted by the contours of the continental shelf off the east coast. In the region of the Grand Banks this water mass makes contact with the waters of the Labrador Current. Once free of the confining influences of the continental shelf, the energy is dispersed as the waters progress across the North Atlantic.

An interesting field for conjecture and investigation is the effect that currents, such as the Gulf Stream and Labrador Current, have on the submarine topography. A depression beneath the path of the Gulf Stream near latitude 32°N. is suggestive of submarine fluid erosion (O'Hare *et al.*, 1954). The transport of suspended material in the waters, and the integrated southerly transport of material by ice and icebergs, must be of considerable magnitude. The deposition of such materials must affect the bottom configuration in some areas.

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TRANSACTIONS OF THE ROYAL SOCIETY OF CANADA
VOLUME L : SERIES III : JUNE, 1956
CANADIAN COMMITTEE ON OCEANOGRAPHY

The Ocean Floor and Water Movement

R. W. TRITES

Introduction

FROM the beginning of systematic study of the currents and circulation in the sea, it was realized that the boundaries constituted important factors in determining water movements. Not only does a boundary affect the motion next to it, since if any motion exists it must be parallel to it, but also the entire circulation of an ocean may be related to or controlled by the boundary conditions.

In recent years increased attention has been given to a study of the air-sea boundary processes, and it has been demonstrated that the wind stress transmitted across the boundary plays an important role in driving oceanic circulations. Proportionately, very little attention has been given to the bottom boundary and the effect of bottom topography on circulation.

The ocean floor is visualized as affecting the water movement in two ways: first, bottom elevations or depressions may limit the direction of flow and provide effective barriers separating water masses; second, for a given transport of water over an irregular bottom, the bottom topography may affect the direction of flow. In the first case the bottom relief merely acts as a boundary preventing motion through it. Frictional forces play no part in this effect. In the second, however, dynamic considerations are all important, and before it is possible to determine the relationship between bottom topography and the direction of transport of water, it is necessary to consider the various forces involved: pressure gradients, Coriolis force, wind stress, and lateral and vertical frictional stresses. This review paper deals mainly with this second aspect of the ocean floor and water movement. In large part, the conclusions drawn are based on the results of mathematical manipulations of the equation of motion. However, only the qualitative results of the mathematical analysis are presented here.

Historical Review

The first theoretical study dealing with the effects of the bottom topography on circulation was undertaken by Ekman (1927). His theory, which was based on a homogeneous sea, considered the following factors in determining the behaviour of flow in a sea of varying depth: friction between the layers of water plus friction along the sea bottom; the horizontal pressure gradient (constant throughout and dependent only on the slope of the sea surface); and the deflecting force of the earth's rotation. Ekman came

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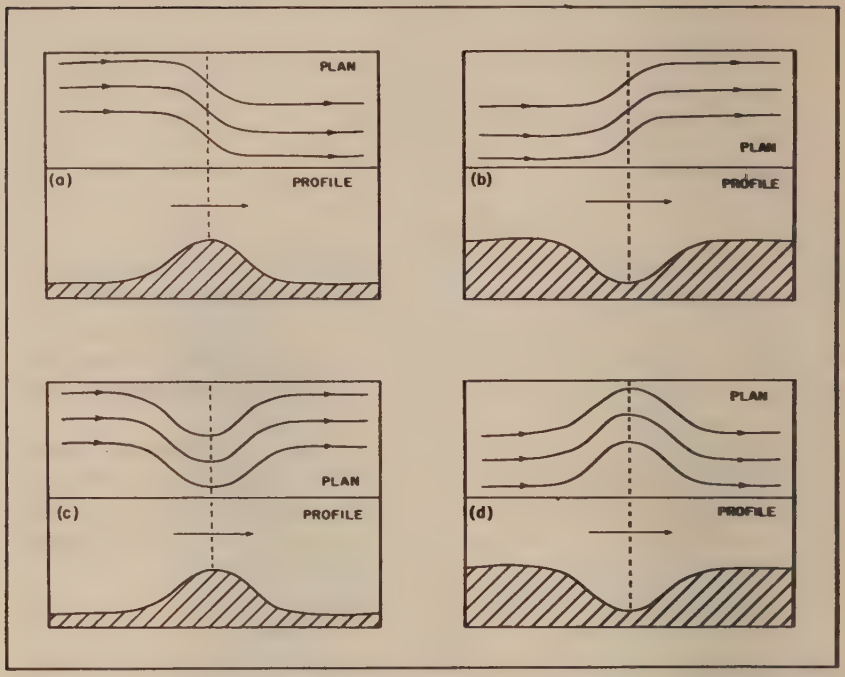

FIGURE 1.—Deflection of a horizontal ocean current (according to Ekman) which crosses (a) submarine ridge, (b) submarine hollow. Deflection of a horizontal ocean current (commonly observed) which crosses (c) submarine ridge, (d) submarine hollow.

to the conclusion that a current in the northern hemisphere, when it passes over an elevation of the bottom, must deviate to the right; and when it passes over a depression of the bottom, must deviate to the left. This is illustrated in Figures 1(a) and 1(b). The situation is just the reverse in the southern hemisphere. The theory indicates that there will be a sideways displacement of the whole current, when passing over a shoal or a deep, and that its magnitude does not depend on the absolute depth of the sea but is determined solely by the slope of the bottom.

Although Ekman's theory indicates a relationship between current flow and bottom topography, it has been found that in most cases the observations do not fit the predicted results very closely. More often the observations appear to fit more closely the situation depicted in Figures 1(c) and 1(d).

Görtler (1941) undertook to improve Ekman's results by considering the Prandtl boundary layer theory, but this did not lead to any qualitative modification of Ekman's conclusions. The significant qualitative disagreement between Ekman's theory and observational data led Sverdrup (1941) to consider the problem from a different point of view. Sverdrup took into account not only the effect of the Coriolis force but also the vertical stratification of the water mass. His reasoning is set forth graphically in the three-

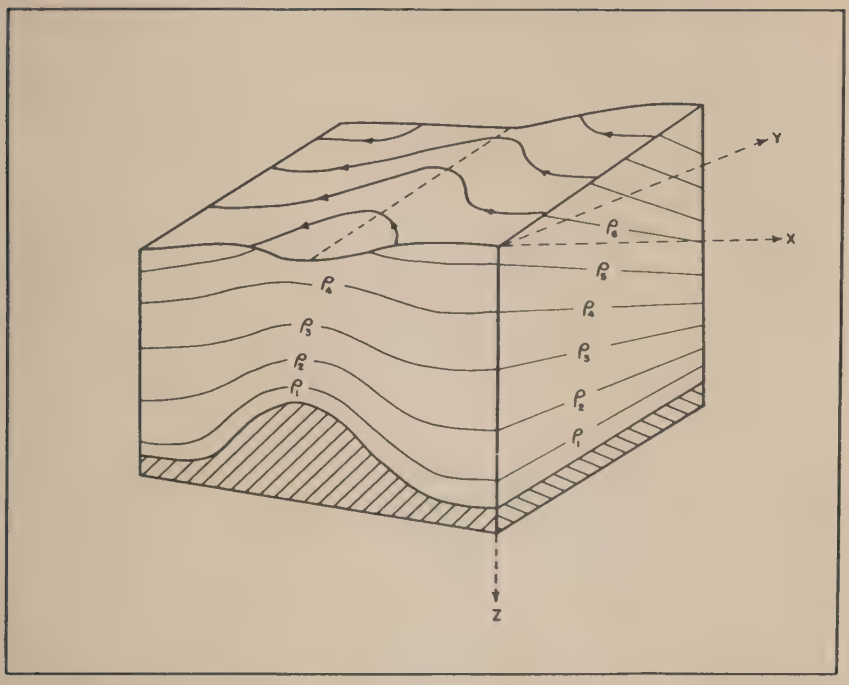

FIGURE 2.—Deformation of isopycnic surfaces and also the sea surface caused by current flowing over a submarine ridge in the northern hemisphere (Sverdrup, 1941).

dimensional diagram of Figure 2, showing the deformation of the isopycnic surfaces and also that of the sea surface, which would be caused by a current flowing at right angles across a submarine ridge in the northern hemisphere.

At some distance in front of the ridge, where the bottom is level, it is assumed that there is no current at the bottom. Consequently, the isopycnic and isobaric surfaces are horizontal near the bottom. With increasing distance from the bottom, the isopycnic surfaces slope, rising from right to left for an observer looking in the direction of the current, while the isobaric surfaces assume the opposite slope. As the stream approaches the ridge the isopycnic surfaces in the layer adjacent to the bottom curve up over the ridge and thus rise; similarly all the way up to the surface. This brings about a lowering of the isobaric surfaces, and of the sea surface itself, along the course of the current, in such a way that right over the ridge there must be a trough-shaped depression in the sea surface. It is evident that the nature of the current is such that as it approaches the ridge it will deviate more and more to the right (in the northern hemisphere) and will reach a maximum over the crest of the ridge. Upon crossing the peak of the ridge, the current will begin to incline to the left, and at some distance away it will once again assume its original direction.

Sverdrup's theory appears to be in excellent agreement with a number of observations, particularly in the Antarctic Circumpolar Current. However, there are a good number of places where it is in complete disagreement with observations. The theory cannot explain why opposite deviations of currents sometimes occur in the *same* hemisphere when passing over an elevation or depression of the bottom, and similar deviations occur for *different* hemispheres. Also Sverdrup's theory cannot account for the absence of deflections in some instances. For example, there is no deviation in the eastward stream at latitude 50°–55°S., although this stream is cutting across the mid-Atlantic ridge just as elsewhere.

Since both Ekman's and Sverdrup's theories fail to explain many of the observations, the question naturally arises as to whether the bottom topography is the only factor determining the nature of the observed deviations or the lack of them.

Shtokman (1947, 1948 a,b) has made a detailed study of the effect of bottom topography on oceanic circulation and, as a result, has developed a new theory which is free of the above-mentioned contradictions and does seem to unite the data into one consistent picture. He considers a non-homogeneous sea and assumes that the ocean currents are determined by the wind stress at the sea surface. Thus the pressure distribution in the sea is related, in part, to the wind. In fact, because of the earth's rotation the slopes of the isobaric surfaces will be the result of an adaption of the pressure gradient to a Coriolis force, set up by an already existing current produced by the wind. In other words, the pressure gradient and density distribution below the sea surface will be a secondary effect of the wind. This is the first fundamental idea underlying Shtokman's theory.

Another point of departure in the theory is the importance placed on lateral friction between layers of water moving side by side. Although vertical friction is also taken into account, the primary stress is placed on lateral friction which Shtokman considers to be one of the most important features of the dynamics of the water of a non-homogeneous ocean. The theory is also based on the fact that in a vertically stratified ocean of sufficient depth, current gradients and velocities are very rapidly damped out with depth. At deeper levels and near the bottom the velocities are practically zero. The rapid decrease in velocity with depth is attributed to the fact that vertical density gradients inhibit vertical turbulence and hence transfer of momentum, whereas large horizontal eddies can develop and transfer energy laterally. Thus to counterbalance the frictional stresses communicated by the wind to the sea surface, it is not necessary that there should be equally large frictional stresses acting along the ocean bottom. The strong horizontal turbulence is capable of transferring a large part of the momentum that has been imparted to the sea by the wind. Shtokman develops his theory by mathematically considering the whole depth, and the vector resultant of transport of the entire water column, rather than by considering the velocities at one depth only.

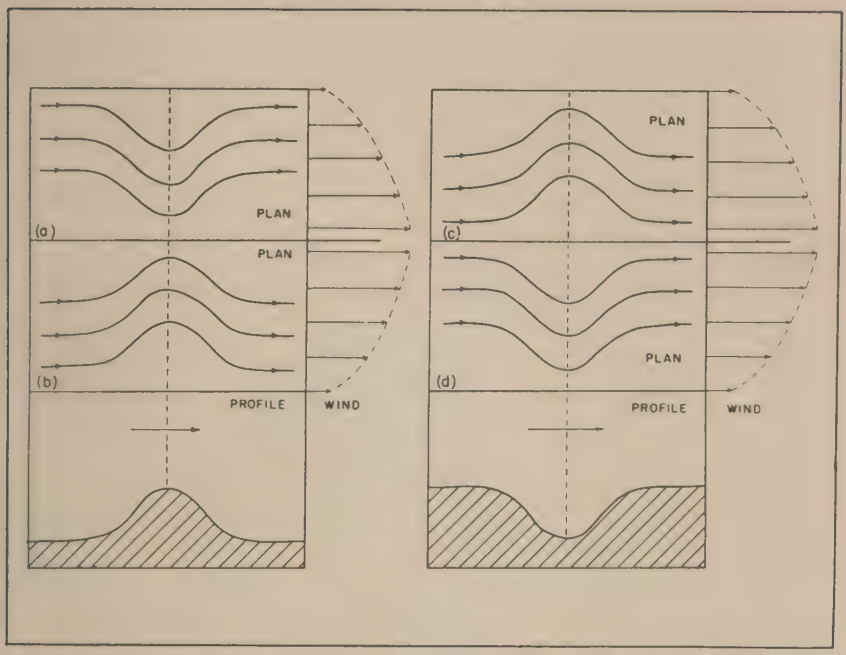

FIGURE 3.—Vertically averaged flow lines as indicated by Shtokman's theory (1947, 1948 a,b) for (a) current crossing ridge, wind increasing, (b) current crossing ridge, wind decreasing, (c) current crossing hollow, wind increasing, (d) current crossing hollow, wind decreasing.

Among the results obtained from his analysis it is important to emphasize that the distribution of mean velocities turns out to be independent of Coriolis force (provided the latter is taken as constant) and is determined solely by the depth and slope of the sea bottom and by the changing state of the wind.

The mathematical results can best be portrayed with the aid of diagrams (see Fig. 3). In Figure 3(a) a plan diagram is shown of the vertically averaged flow lines of a current crossing a bottom elevation with the wind speed increasing from left to right (looking in the direction of the current). In Figure (b) the lines are drawn as if the wind was decreasing from left to right. Figures 3(c) and 3(d) show the effect on a current flowing over a depression in the bottom for the same wind conditions as in Figures 3(a) and 3(b). Thus one finds that in Shtokman's theory the flow-line deviations may be the same no matter what the geographical position of the submarine hump or hollow, provided the transverse gradient of the wind velocity has the same sign.

To give a physical explanation to the theoretical results, one must have recourse to the concept of the *vorticity* of a fluid. This can be visualized physically by considering that at some point in a moving fluid an infinitely

small paddle-wheel has been placed. If the paddle-wheel rotates, then the fluid has a vorticity which is measurable by the angular velocity of the paddle-wheel. Thus one can see that velocity gradients must exist if a fluid is to have vorticity. It should be noted, however, that a flow may have vorticity when its motion is linear, and also that flow lines may be circular without vorticity.

Consider a vertical column of water of unit cross-sectional area moving between two stream lines in Figure 3(a). Suppose the wind stress at the surface to be constant in the direction of flow, but to vary transversely. The water column will have a certain vorticity at some position to the left of the hump. As the water moves over the hump, the column is decreased in length. Consequently, the vorticity of a column of unit cross-sectional area is different from that of a column in deeper water. It is this change in vorticity which results in a deviation of direction as water moves over a hump or a hollow.

Shtokman has tested his results using data from many different geographical areas and finds good qualitative agreement in all cases. In particular he applied his theory to the sub-tropical area of the South Atlantic, where the ocean bed is characterized by a number of humps and hollows in the directions of the prevailing winds. The results, which reproduce the main features of the South Atlantic circulation, indicate a number of large eddies with centres located over bottom elevations. It is important to emphasize that the eddies form not over bottom depressions, as would follow from Sverdrup's theory, but over bottom elevations. This situation would tend to favour the accumulation of particulate matter on the elevations rather than in bottom depressions.

To summarize Shtokman's conclusions one can say that when a current crosses an elevation in the bottom, the flow lines deviate over the summit in the direction of increasing wind stress. When passing over a depression the flow lines deviate in the direction of decreasing wind stress.

Circulation and Bottom Topography of the Scotian Shelf

On the basis of the preceding discussion it is interesting to speculate as to the relationship between the bottom topography and water movements on the Scotian Shelf. The submarine physiography of the Scotian Shelf and its effect on water movements has been discussed previously in some detail by Hachey and others (Hachey, 1937, 1953; Leim and Hachey, 1935; *et al.*, 1954). The importance of the physiography, particularly as a barrier in preventing certain flows or as a channel in permitting certain other movements on the Shelf, has been emphasized in these papers.

A glance at Figure 4 reveals the main features of the bottom topography of the area off the Nova Scotian coast. The Scotian Shelf is an irregular-shaped submarine plateau extending outward from the coast to a distance of 100 to 150 miles. The Shelf is separated from the Grand Banks by the

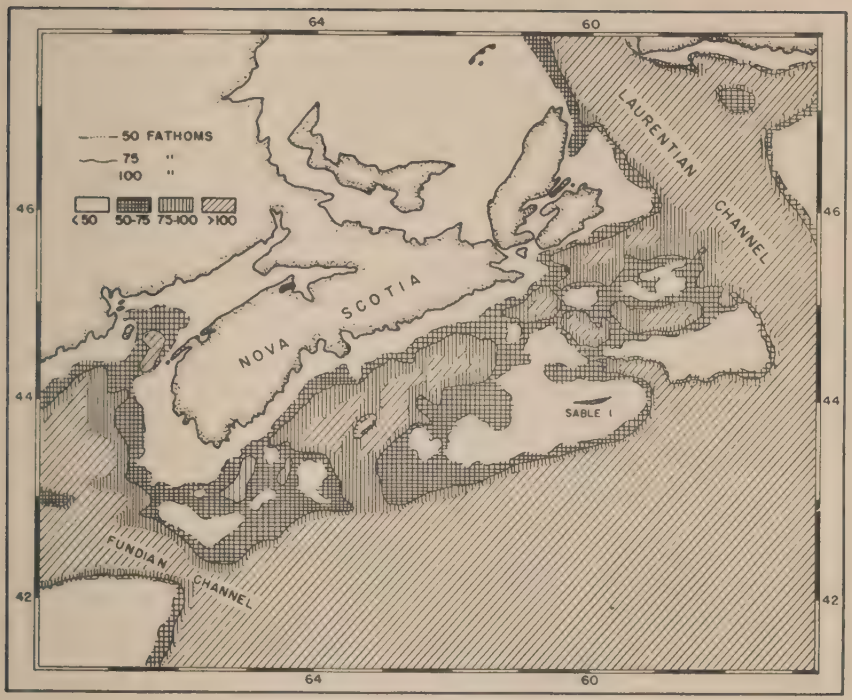

FIGURE 4.—Bottom topography of the Scotian Shelf.

Laurentian Channel, and from Georges Bank by the Fundian Channel. With the exception of several basins, the Scotian Shelf is less than 100 fathoms below the sea surface.

A fairly large basin in the central part of the Shelf is more than 100 fathoms below the sea surface. The greatest depth of the channel connecting this with the deep water off the Shelf is only slightly more than 75 fathoms below the sea surface. There are a number of small elevations (banks) whose depths are less than 50 fathoms below the sea surface, and two particularly large banks, one surrounding Sable Island and the other to the east of it (Banquereau).

Hachey and others have indicated the important role that the shelf topography plays in determining the movement of water at depths of 50 fathoms or greater. There is fairly conclusive evidence that the elevations and depressions of the bottom restrict or channel the flow. This is an example of one way in which bottom topography and water movements are related, as mentioned earlier in this article. But, does the irregular bottom topography of the Scotian Shelf affect the direction of total transport? This would seem to depend upon whether or not the water column has vorticity, and whether the flow varies in thickness corresponding to the bottom topography.

The circulation of water on the Scotian Shelf is not particularly well known. However, there is considerable evidence that the net surface currents near the Nova Scotian coastline are to the southwest, and, further out from the coast in the vicinity of the 100-fathom contour, to the east. There is also some evidence of a large cyclonic eddy centred on the Sable Island bank area. To what extent the surface circulation is governed by the wind stress at the sea surface is not known. The dynamics of the circulation may be related predominately to the mass field and the lateral boundary conditions, with wind stress locally playing only a minor role. However, it is conceivable that, whether the wind imparts vorticity to the water column or the water has vorticity upon entering the shelf, the circulation, even at the surface, may be profoundly influenced by the bottom topography. Is the evidently cyclonic circulation around Sable Island bank evidence of this? At the moment, this question cannot be answered; to do so will require many field observations.

Summary and Conclusions

Three theoretical approaches to the problem of relating bottom configuration to water movement have been reviewed. Of these, Shtokman's results are the most convincing, and unite the field data into one consistent picture. For wind-driven oceanic transports over an irregular bottom Shtokman's theory indicates that: (1) The deviation is independent of the Coriolis force. (2) The deviation is dependent on the wind stress variation at the sea surface, which imparts vorticity to the water column. (3) The deviation depends on the slope of the bottom and is inversely proportional to the depth of water.

A brief discussion of the physiographic features of the Scotian Shelf has also been given. It is evident that the bottom configuration acts either to channel or to prevent certain movements, but whether, in some areas, there is flow over an irregular bottom causing a deviation in the flow lines, is not known.

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Classification of Daily Sea-Water Data

Susumu Tabata

Abstract—A method is presented for classifying daily observations of sea-water temperature and salinity at five light stations along the coast of British Columbia. In order to summarize the large masses of data collected during the 15 years, 1940–1954, the monthly means are compared to the grand monthly means by passing them through a step filter whose jumps are chosen from integral multiples of the standard deviations. Examples of the use of this classification are also shown.

Observations of temperature and salinity of the face waters of the British Columbia coast have n made daily at several coastal light stations for ying periods since 1914. They are published ually in manuscript series by the *Pacific Oceano- phic Group of the Fisheries Research Board of nada* [1944–1954].

Utilizing these data, *Pickard* and *McLeod* [1953] ve made a preliminary analysis of the general nds of temperature and salinity along this coast ng grand monthly means through 13 years and ve described their annual cycles in terms of own geophysical principles. Several descriptive re- rts on these observations have also been made by lly [1937, 1938, 1950, 1952] and *Hollister* [1949, 51, 1952]. A good deal of the data is currently ing used by fisheries biologists in correlating with e abundance or scarcity of particular marine ecies in the region.

Frequently large masses of data need to be ex- ined and periods of abnormality isolated before ch correlations can be made. It appears that the alysis may be facilitated if the data can be mmed up by constructing a filtering device that uld classify them. In order to provide such a ter the 15 years of data (1940 to 1954 inclusive) e classified using integral multiples of standard viations.

Daily observations of sea-water temperature d salinity are made at a depth of three feet at the ne of high tide occurring during the daylight urs. Each day's observation is about three- arters of an hour later than the previous one. he time of observation therefore progresses rough the day from about 07h 00m to 19h 00m about two weeks, and variations due to diurnal fects are inevitable. Because observations are ade near the shore, they do not necessarily repre- nt the oceanographic conditions away from the ore. Furthermore, the declination effects on the des and the tidal mixing associated with the dal currents probably affect the data. But by king monthly means these effects are minimized, and this period seems to be appropriate for analyses.

Some authors have grouped natural conditions according to arbitrary limits chosen after careful study. An example of this is *Easton's* [1928] classification of winters in Europe. Such classification, though adequate in some individual time series, is not generally satisfactory because it may not be applicable or comparable to other series. There is also a lack of objectivity in the selection of the limits. However, if limits are derived from statistical elements, most of the objections disappear. *Conrad* [1953] has separated severe and mild winters in Europe by using standard deviations as a deciding limit in the classification.

The daily sea-water observations made in British Columbia represent a number of individual time series. The limits of the significant variations of these series vary with stations and with seasons; for instance, a fluctuation of temperature of a few degrees may be considered as normal and random at one station while it may be very significant at another. The same reasoning applies to fluctuations in different seasons. These considerations led to the use of a statistical filter.

Method of classification—Although records are available from some localities for more than 20 years, the data from most of the stations from about 1940 onward appear to be most consistent. In this study only the data from 1940 to 1954 inclusive from each station are considered so that they have equal statistical weight.

The grand monthly means obtained from 15 years of observation are assumed to represent the average state during this period. Actually, if data are available, an average based on a longer period may be more stable since the means are likely to be more stable.

The magnitudes of the monthly means are compared to the grand monthly means by passing them through a step filter whose jumps are chosen from commonly used multiples of the standard deviations (σ, 2σ). The resulting codification is shown

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TABLE 1 – *Statistical limits used in classification*

Code Letter	Limits	Remarks
+C	$>+2\sigma$	Much above average
+B	$+\sigma$ to $+2\sigma$	Above average
+A	Mean to $+\sigma$	Average
A	Mean	
−A	Mean to $-\sigma$	
−B	$-\sigma$ to -2σ	Below average
−C	$<-2\sigma$	Much below average

in Table 1. This is a coarse filter, but if a more
tailed treatment is required the steps can
arranged in multiples of $\sigma/2$.

Discussion—The grand monthly mean value
the sea-water data and their standard deviat
at five of the stations (Fig. 1) from the 15 ye
data (1940–1954) are shown in Tables 2 and 3
the classified data on Figures 2 and 3.

It is fairly easy to select the periods of maxim
deviations of temperature and salinity that
curred at these stations during the last 15 ye

FIG. 1 – Chart showing location of light stations Langara, Triple, Ivory, Pine, and Kains

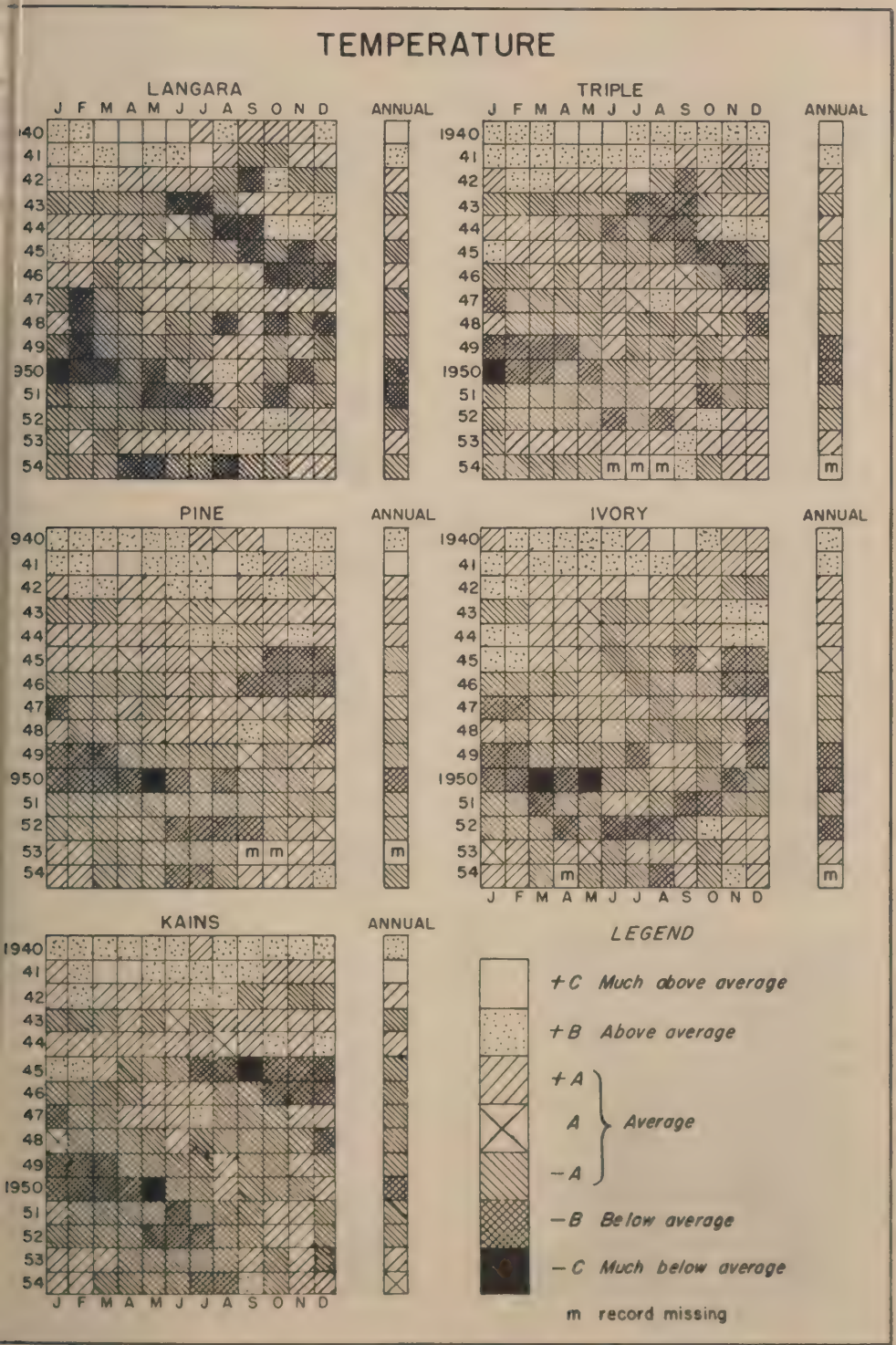

FIG. 2 – Classification of sea-water temperatures at the five light stations for the period 1940 to 1954

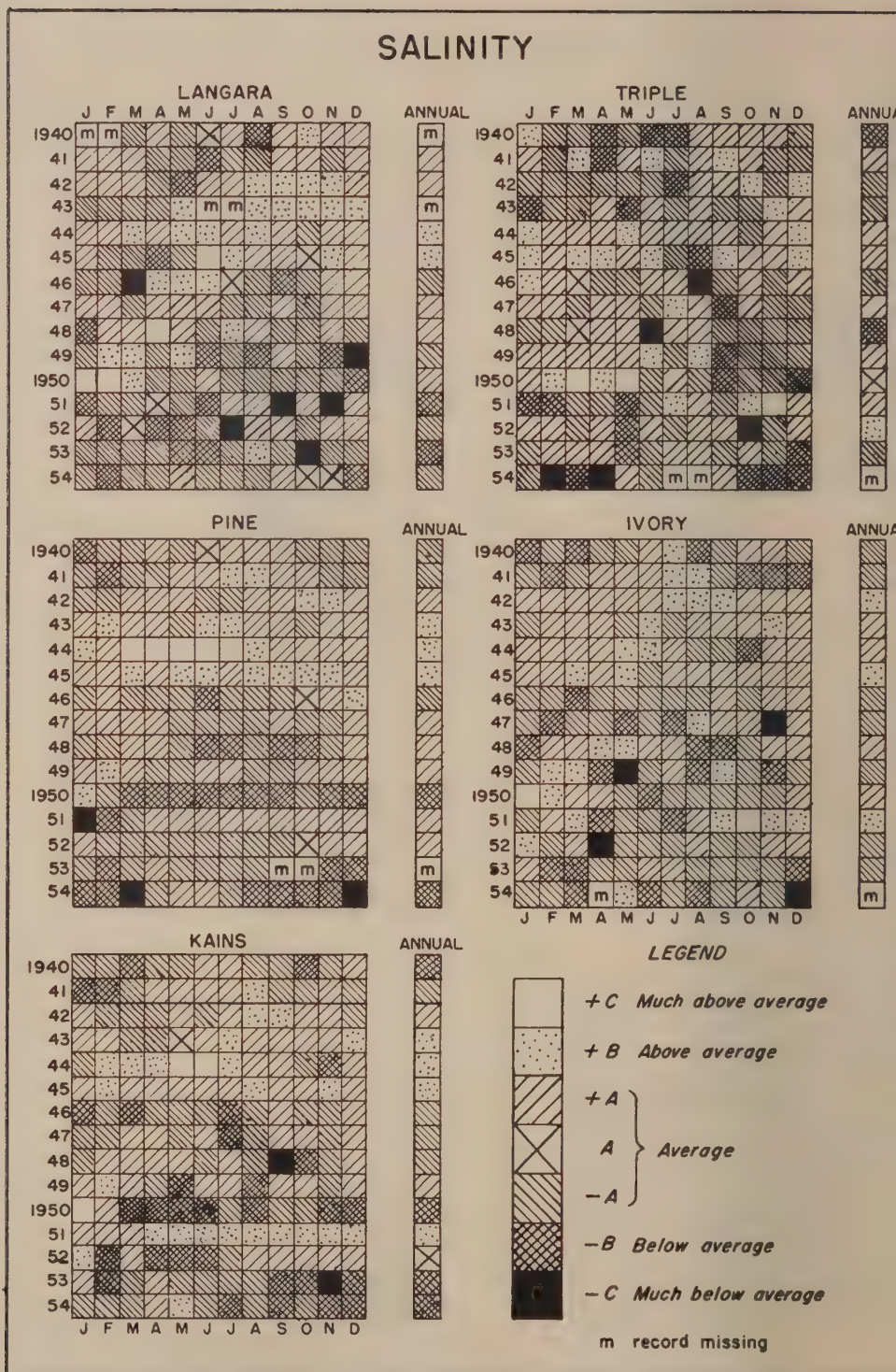

FIG. 3 – Classification of salinity at the five light stations for the period 1940 to 1954

E 2 *Grand monthly means* (T) *and standard deviations* (σ) *of the surface sea temperatures* (°F) *at five light stations, 1940–1954*

ght station	Item	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec
Langara	$\bar{T}$	43.1	42.8	43.3	44.7	47.2	49.6	52.2	52.7	52.5	51.1	47.4	44.9
	σ	2.3	1.8	1.6	1.4	1.2	1.1	1.2	1.5	1.2	0.9	1.4	1.6
Triple	$\bar{T}$	44.4	43.7	43.6	44.8	47.9	51.9	54.3	54.6	52.9	50.7	48.2	46.2
	σ	2.3	2.0	1.9	1.6	1.4	1.2	1.1	0.8	0.8	0.6	1.1	1.6
Ivory	$\bar{T}$	43.6	43.2	43.9	46.4	50.7	54.9	57.7	58.1	56.1	51.7	47.6	45.0
	σ	1.7	1.6	1.4	1.8	1.3	1.2	1.1	0.7	1.1	0.7	1.2	1.5
Pine	$\bar{T}$	45.4	45.0	45.2	46.1	47.5	48.8	49.9	49.8	49.5	49.4	48.3	46.5
	σ	1.2	1.4	1.2	1.3	1.1	0.8	0.7	0.5	0.5	1.0	1.4	1.0
Kains	$\bar{T}$	45.9	45.5	46.2	47.7	50.3	52.8	54.8	55.6	55.3	52.7	49.4	47.3
	σ	2.1	1.8	1.5	1.6	1.2	1.4	1.4	1.0	1.4	1.0	1.5	1.6

LE 3 - *Grand monthly means* (S) *and standard deviations* (σ) *of the surface salinities* ($S‰$) *at five light stations, 1940–1954*

ight station	Item	Jan	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Langara	$\bar{S}$	32.21	32.27	32.26	32.32	32.32	32.30	32.18	32.24	32.15	32.16	32.01	32.08
	σ	0.27	0.16	0.18	0.14	0.11	0.20	0.15	0.24	0.38	0.32	0.15	0.21
Triple	$\bar{S}$	31.72	31.76	31.79	31.75	30.67	28.98	29.50	30.18	30.84	31.39	31.55	31.69
	σ	0.29	0.27	0.20	0.28	0.57	1.16	0.93	0.58	0.35	0.40	0.24	0.27
Ivory	$\bar{S}$	29.79	29.87	29.96	29.23	28.94	27.51	26.45	26.59	27.47	27.50	28.28	28.81
	σ	0.78	0.67	0.75	1.04	0.91	1.28	1.12	1.28	1.40	1.37	0.94	0.82
Pine	$\bar{S}$	31.42	31.40	31.54	31.68	31.79	31.87	31.79	31.86	32.01	32.04	31.75	31.50
	σ	0.31	0.27	0.25	0.21	0.19	0.23	0.21	0.18	0.25	0.20	0.31	0.36
Kains	$\bar{S}$	29.53	29.32	29.89	30.14	30.61	31.40	31.82	32.10	31.69	30.50	29.64	29.02
	σ	0.73	0.88	0.76	0.69	0.60	0.37	0.44	0.36	0.56	0.87	0.97	0.77

ere is a marked difference between the tempera-
es in the period a decade apart (Fig. 2). In the
rs 1940 and 1941 the temperatures are con-
ently greater whereas in 1950 they are lower
n the means.

There appears to be a coherence in the tempera-
e events; that is, the warmer months are fol-
ed by warmer months, the colder by colder
nths, and so on. This is similar to meteorological
nts which tend to cohere rather than occur as
lated incidents [*Brooks* and *Carruthers*, 1953].
ey not only persist from month to month but
d to cluster from year to year. Apart from this,
obvious trend in the year to year variations
uld be detected. A more or less similar type of
herence occurred in the salinity events. In the
rs 1943 and 1944 the water was generally more
line and in 1953 and 1954 it was less saline than
e means.

The classification of these variables is a method-
gical example of grouping the data and deter-
ining their major variations, but it provides an
sy reference for outlining the general oceano-
aphic state.

In the investigation of marine life, the reason for
currence or absence, or for fluctuation in abun-
dance, of species is frequently sought in terms of oceanographic conditions. Various topics on the physical conditions in the sea in relation to fishes, such as temperature and salinity relating to spawning, temperature, and development of larvae, etc., have been discussed by *Tait* [1952]. *Ketchen* [1956] showed correlation between monthly mean sea temperatures and the sizes of year-classes of groundfish in Hecate Strait.

The present classification would provide a quick way of recognizing the first-order correlation and may be used as a guide for a more detailed study.

When series of quasi-synoptic oceanographic surveys extending for a period of a month or so are made in a locality, one of the routine analyses involves the examination of the seasonal variations during that period. There are instances where the situation is generalized and conjecture made that the condition is typical. In some cases such assumptions are justified, but in others the conditions may be exceptional rather than typical. It may be possible that the classification of daily sea-water data may facilitate the generalization of such cruise data.

In Table 4 is shown the classification of the surface sea-water temperature and salinity during

TABLE 4 - *Classification of monthly sea-water data during Hecate cruises 1954–1955*

Item	Station	1954												1955							
		J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A
Temperature (°F)	Langara	−A	−A	−A	−B	−B	−A	−A	−B	−A	−A	+A	+A	+A	+A	−A	−A	−B	−B	−C	−A
	Triple	A	−A	−A	−A	−A	−	−	−	+B	−A	+A	+A	+A	+A	−A	−A	−A	+A	−A	−C
	Pine	+A	+A	−A	−A	−A	−B	−B	−A	+A	+A	+A	+B	−A	+A	−A	−A	−A	+A	−B	−B
	Ivory	+A	+A	−A	−	−A	−A	−A	−B	+A	+B	−A	+A	+B	+B	+A	−A	−B	−A	−A	−A
	Kains	+A	+A	−A	−A	−A	−A	−B	−B	+B	−A	+A	+A	+A	−A	−B	−A	−B	−B	−B	−C
Salinity (‰)	Langara	−A	−B	−A	−A	+A	−A	−A	−A	+A	A	A	−B	−A	−C	−A	−C	−C	−C	−A	−A
	Triple	−A	−C	−B	−C	+A	−A	−	−	+A	−B	−B	−B	+A	−C	−B	−B	+B	+A	−C	−A
	Pine	−B	−B	−C	−A	+A	+A	−A	−B	−B	−B	−B	−C	−B	+A	+B	+B	+B	+B	+B	−A
	Ivory	−A	−A	−B	−	+B	−B	−A	−B	−A	+A	−A	−C	−B	−B	+A	+A	+A	+A	−A	−B
	Kains	−A	−A	−A	+A	+B	−A	−B	−A	−B	−A	−B	−B	−A	+A	+C	+B	+B	+A	+A	−A
	Cruise numbers				↑	54-1→		54-2→	54-3→			54-4→			55-1→		55-2→		55-3→	↑	

ary 1954 to August 1955 relative to the aver-
onditions of the previous 15 years. During the
d of the surveys, the daily sea-water data
ate that the sea temperature was generally
and the salinity also less than those of the
ctive means of the previous 15 years. The
r was particularly colder in the summer of 1954
somewhat warmer in the winter of 1954–1955.
ity was also lower in the summer of 1954 but
s marked as in the winter of 1954–1955 when
s particularly low. This latter is probably the
outstanding feature of the difference in the
itions from that of the means. One interesting
re of this less saline water is that it occurred
st in the southern stations.

ice the summer temperature was lower and
vinter temperature higher than the means, the
litude of the annual cycle was small, and there-
the conclusion based on these as representing
ge states could be misleading.

Pine Island the salinity was low in the latter
of 1954 but was high in the first half of 1955.
the annual amplitude was much larger than
average year and could not be considered as
al of the average state.

ese are examples in which the classification
be used. It defines both the normal years when
itions are most representative and abnormal
s when some peculiarities may have occurred.
lso provides indices of the general oceano-
hic condition in the region, and cruise data
cted during any given time may be referred to
e and suitable adjustment made on these data
generalization.

hen large amounts of data are to be processed
examined, as in the case of daily sea-water
rvations, this method has a particular advan-
in the relative ease in which classification and
comparison can be made.

cknowledgments—The author is indebted to D. A. and K. H. Austin for executing many of the cal-ions and to J. P. Tully for his valuable suggestions criticisms during the course of the investigation.

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(Communicated manuscript received December 5, 1955, and, as revised, August 21, 1956; open for formal discussion until September 1, 1957.)

THE GROSS AND MICROSCOPIC ANATOMY OF THE DIGESTIVE TRACT OF THE OYSTER CRASSOSTREA VIRGINICA (GMELIN)[1]

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Abstract

The gross and microscopic anatomy of the digestive tract of *Crassostrea virginica* (Gmelin), the common oyster of commerce of the North Atlantic Coast, is described. The dorsoventrally compressed mouth bounded by two pairs of labial palps leads into a crescentic oesophagus, thence to the anterior chamber of the stomach from which a complex caecum extends into anteriorly and posteriorly directed spiral appendices. The posterior chamber of the stomach bears a chondroid gastric shield and leads into an elongated chamber which is incompletely divided by two typhlosoles into a style-sac and mid-gut. The intestine is divisible into ascending, median, and descending limbs, the latter merging into the rectum which terminates on the dorsal surface of the adductor muscle. Extensively branched tubular digestive diverticula exit from the stomach by a series of ducts along the margin of the caecum and the posterior stomach. The complete digestive tract is lined by a simple columnar epithelium which is ciliated throughout with the exception of the upper lip or fused external palps, the lower side of the gastric shield in the posterior stomach, and the tubules of the digestive diverticula. Mucous secreting and eosinophilic epithelial cells occur in varying numbers along the course of the tract. Phagocytes are present between the lining epithelial cells, among the peripheral collagenous and muscle fibers, as well as in the lumen of the tract. The gastric shield is shown to be intimately attached to the underlying epithelium by a central clip as well as by minute cytoplasmic processes. The anatomical relationships are compared with various lamellibranchs including the Chilean oyster, *Ostrea chilensis* Philippi; the European oyster, *Ostrea edulis* L.; and the Portuguese oyster, *Gryphea angulata* Lamarck.

Introduction

Crassostrea virginica (Gmelin), the Atlantic coast oyster of commerce, occurs intermittently in coves, bays, and estuaries, and at the mouths of tidal rivers along the eastern seaboard of North America from the south shore of the Gulf of St. Lawrence to the Gulf of Mexico. Although Clark (1920 (6)) has made the statement that the oyster is the best known marine animal in the world, both physiological and pathological investigations have been seriously curtailed by the inadequacy of descriptive data relative to its gross and microscopic anatomy. Brooks (1880 (4)) in a brief account of the development of the oyster *Crassostrea* (*Ostrea*) *virginica* described the visceral mass as comprising a folded oesophagus, an irregular stomach surrounded by a dark greenish "liver", and a convoluted intestine. Ryder (1880 (26)) subsequently outlined the course of the digestive tract of the same species referring to the internal foldings of the stomach, the course of the intestine, and the extent of the "liver". Dahmen (1923 (7)) gave a comprehensive account of the gross structure of the tract of *Ostrea chilensis*

[1]Manuscript received February 18, 1957.
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[2]This paper is based in part upon a thesis submitted by the senior author in partial fulfilment of the requirements for the degree of Master of Science at the University of Western Ontario, 1954.

Philippi and also referred to its histology. In an introduction to a physiological study of *Ostrea edulis* L., Yonge (1926 (33)) described the gross anatomical relationships of the tract briefly and the microscopic anatomy in somewhat more detail. Leenhardt (1926 (17)) dealt largely with the histological structure of the tract of the Portuguese oyster, *Gryphea angulata* Lamarck (*Crassostrea angulata* Gunter, (1950 (14)), and made only minor references to gross anatomical relationships. The present study of the digestive tract of *Crassostrea virginica* was accordingly undertaken because of the paucity of data on both the gross and microscopic anatomy of the oyster and of this species in particular.

Materials and Methods

All oysters used in this investigation were obtained from Malpeque Bay, Prince Edward Island, Canada. Initial dissections were carried out on fresh specimens as well as following preservation and hardening in 5% formalin. The gross anatomical relationships of the lumen of the tract were determined from casts made by injecting alkaline latex or vinylite resin through the mouth and the anus of fresh specimens and subsequently removing the surrounding tissues.

For histological studies, the relative merits of a number of the more common fixatives were determined and, of these, Davidson's solution of the following formula proved most efficacious:

formalin (analytical reagent 35%)	20 parts
glycerin	10 parts
alcohol, 95%	30 parts
glacial acetic acid	10 parts
water (sea water where available)	30 parts

After fixation for 24 hours, specimens were stored in a solution of the same formula minus the glacial acetic acid. Following dehydration, toluol was employed for clearing and Tissuemat of melting point 60° to 62° C. for imbedding. Sections were cut at 5 to 10 μ and stained with Erhlich's haematoxylin and Triosin (Galigher, 1934 (12)), iron haematoxylin, Mallory's triple stain, Van Gieson's picrofuchsin, and cresyl echt violet.

Newly-set spat from less than 1 mm. to 10 mm. in length were fixed in Bouin's fluid and cleared in creosote or clove oil with or without prior staining in alum-cochineal. Serial sections cut at 10 μ were counterstained with light green.

Gross Anatomy of the Digestive Tract

Terminology

The terminology of Pelseneer (Nelson, 1938 (23)) with regard to the axes of symmetry of the oyster will be followed in this paper. Accordingly the principal axis of the oyster lies in a line drawn through the mouth and the anus. The hinge is anterodorsal, the palps and forward portions of the gills project ventrad, while the hinder portions of the gills extend both ventrad and posteriorly.

General Anatomical Relationships

The right valve of *Crassostrea virginica* is flattened and usually uppermost in naturally-setting spat, while the left valve is cupped toward the hinge to accommodate the visceral mass. Removal of the right valve exposes the right lobe of the mantle, whose thickened and darkly pigmented free margin bears minute tentacles. The single adductor muscle is located slightly posterior to a line bisecting the principal axis and somewhat nearer the dorsal than the ventral margins of the valves. The crescentic posterodorsal division of the muscle is composed of smooth fibres, while the anterior "catch" division consists of striated fibers (Yonge, 1926 (33)). On the removal of the right lobe of the mantle (Fig. 1), the visceral mass, the gills, and the pericardial cavity are exposed. The visceral mass is ovoid anteriorly and forks posteriorly. The ventral branch is triangular with its apex extending to the mid-level of the adductor muscle. It comprises a posterior diverticulum of the stomach, the so-called style-sac, fused lengthwise with the first segment of the intestine or the mid-gut, as well as the ascending or recurrent limb of the intestine. The cylindrical dorsal branch of the visceral mass encloses the rectum, which terminates on the dorsal margin of the adductor muscle. The ventral anterior margin of the visceral mass is surmounted by two pairs of labial palps whose posteriorly-directed free ends overlap the anterior margins of the gill plates.

Labial Palps and Mouth

The labial palps are roughly triangular plates with an acute apex directed posteriorly (Figs. 1 and 2). Their ventral margins are somewhat crescentic while the dorsal margins are straight and fused anteriorly to the ventral surface of the visceral mass. The outer pair are slightly larger than the inner pair and, except at the anterior roots, are entirely free from the inner palps. The lateral surfaces of the external palps and the medial surfaces of the internal palps are smooth or plane. The adjacent medial surfaces of the external palps and the lateral surfaces of the internal palps are coarsely fluted with ridges directed obliquely towards the mouth opening. The latter takes the form of a dorsoventrally compressed slit at the outer margin of the valve-hinge extremity of the body. Ryder (1880 (26)) described it as appearing between the upper median angles of the palps. The outer pair of palps extend anteriorly and dorsally around the mouth where they fuse in the form of a hood or upper lip. The inner palps are united with each other along their mid-dorsal line for one-half or more of their length and their fused anterior ends are elevated as a fleshy ridge or lower lip. Dahmen (1923 (7)) and Yonge (1926 (33)) have also shown, for *O. chilensis* and *O. edulis* respectively, that unlike the majority of lamellibranchs, these species have the inner and outer palps of the two sides fused in the region of the mouth. In addition, however, in the latter species the outer palps are united for one-fourth of their length so that the mouth is entirely enclosed.

Mouth Cavity and the Oesophagus

The mouth opening leads into an elongated dorsoventrally flattened mouth cavity (Fig. 19). Ryder (1880 (26)) noted that "the mouth is so wide the animal can scarcely be said to have an oesophagus". Leenhardt (1926 (17)) described an elongated passageway between the oral opening and the anterior oesophageal orifice in *G. angulata* and suggested its analogy to a pharynx. The presence of this passageway would appear to be a characteristic of the genus *Crassostrea*, since in *O. chilensis* (Dahmen, 1923 (7)) and *O. edulis* (Yonge, 1926 (33)) the mouth leads directly into a short oesophagus. In *C. virginica* the oesophagus arches posterodorsally at an angle of approximately 45 degrees to the long axis of the palps. It measures approximately one-fifth of the maximum anterior–posterior length of the visceral mass and enters the anterior chamber of the stomach at the junction of the latter with the caecum (Figs. 3, 4, 5).

Stomach

The stomach (Figs. 3, 4, 5, 21, 22) is a saccular organ centrally located in the posterior two-thirds of the ovoid portion of the visceral mass. It is completely surrounded by the greenish-brown tubules of the digestive diverticula. The stomach proper is divisible into a smaller anterior chamber grading into a somewhat larger posterior chamber. The anterior chamber appears as an enlargement at the base of the oesophagus. An extensive complex outpouching or caecum arises from its left ventral surface, and takes the form of an oblique channel, with spirally directed anterior and posterior limbs or appendices. The anterior appendix is smaller than the posterior appendix and projects dorsad along the base of the oesophagus (Fig. 4). It comprises one and one-quarter to one and one-half turns which follow a counterclockwise direction. The large posterior appendix appears bandlike

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FIG. 1. Gross anatomical relationships of *C. virginica*, as viewed with the right valve and the right mantle removed. The visceral mass is heavily outlined. A.M., adductor muscle; G.P., gill plates; L.MA., left mantle; L.P., left labial palps; L.V., left valve; P.C., pericardial cavity; V.M., visceral mass.

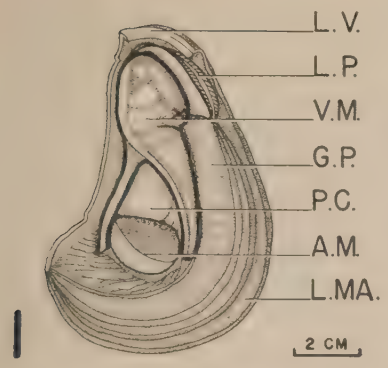
FIG. 2. Mouth opening from the anteroventral aspect, with the inner and outer labial palps spread laterally. I.P., inner labial palp (left); L.L., lower lip; M., mouth; O.P., outer labial palp (left); R.S., ridged surfaces; U.L., upper lip.

FIG. 3. Latex mold of the lumen of the digestive tract, exclusive of the tubules of the digestive diverticula, viewed from the right lateral aspect. A.I., ascending limb intestine; A.M., adductor muscle; C.D., caecal ducts of digestive diverticula; D.I., descending limb intestine; M.I., median limb intestine; O., oesophagus; P.C., pericardial cavity; P.D., posterior gastric ducts of digestive diverticula; R., rectum; S., stomach; S.S.M.G., style-sac and mid-gut.

FIGS. 4 and 5. Latex mold of the lumina of the oesophagus and stomach viewed from the left lateral aspect (Fig. 4) and the left ventral aspect (Fig. 5). A.C., anterior appendix of caecum; C.D., caecal ducts of digestive diverticula; G.R., gastric ridges for attachment gastric shield; M.G., mid-gut; O., oesophagus; P.C., posterior appendix of caecum; P.D., posterior gastric ducts of digestive diverticula; P.S., posterior chamber of stomach; S.S., style-sac.

FIG. 6. Dissection of the stomach with the right wall removed to show the internal ridges and gastric shield in situ. A.S., anterior chamber of stomach; G.S., gastric shield; L.P., labial palps; O., oesophagus; P.S., posterior chamber of stomach; S.S., style-sac.

FIG. 7. Typical gastric shields; (*a*) left lateral aspects, (*b*) medial aspect. A.L., anterior lobe; F.M., flexed margins forming clip; N., neck; P.L., posterior lobe.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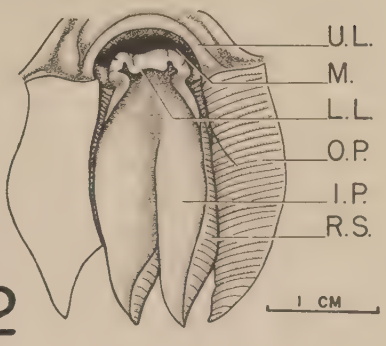
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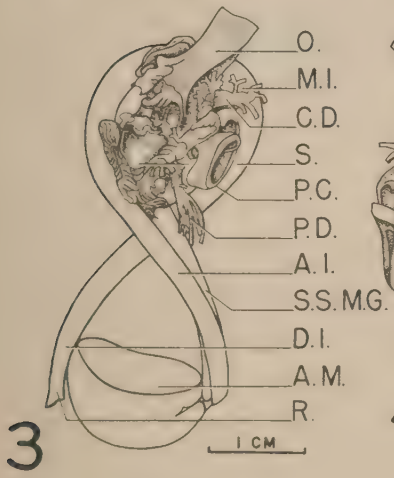
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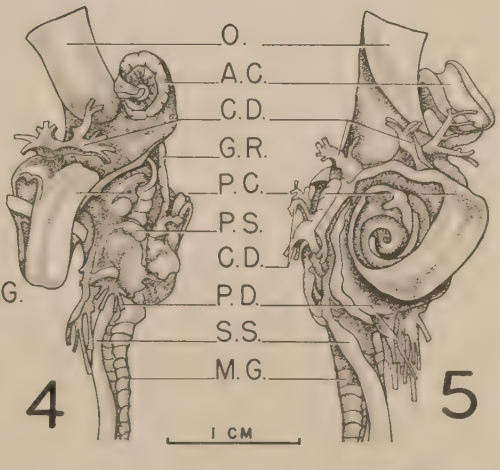
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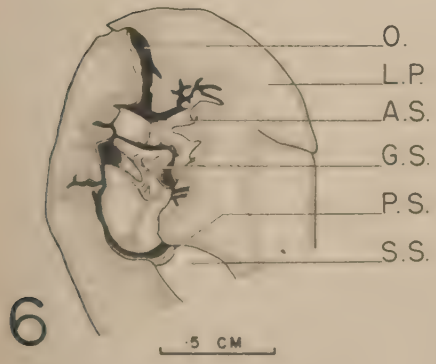
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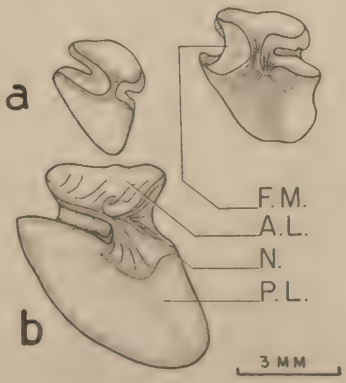
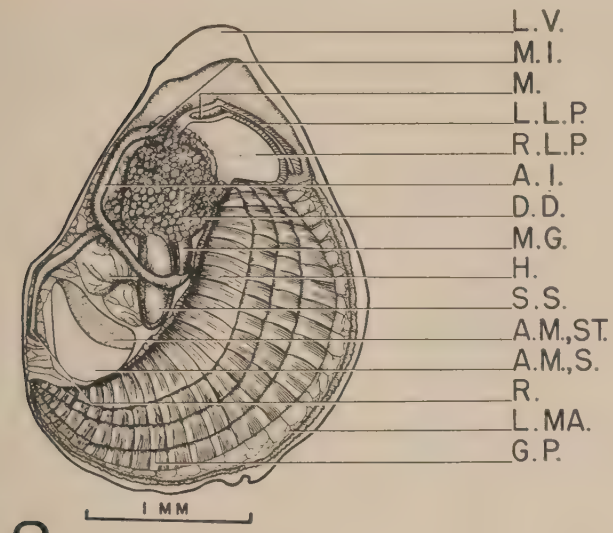

a
F.M.
A.L.
N.
P.L.
7
b
3 MM

and is directed ventrally and toward the right of the stomach. It consists of one and one-quarter turns which extend in a clockwise direction. The peripheral walls of the appendices are invaginated as typhlosoles, while the walls adjoining the anterior stomach are flattened and approximate each other.

Ryder (1880 (26)) described the stomach of *C. virginica* as an organ with prominent transversely directed internal folds, two of which lie in a ventral position and take the form of inward projecting lobes "which are themselves lobulated", and presumably correspond to the caecum and its appendices. Dahmen (1923 (7)) indicated that the stomach of *O. chilensis* is divisible into an anterior dorsal and a wide posterior chamber, the left side of which extends into anterior and posterior blind sacs. Yonge (1926 (33)) illustrated the stomach of *O. edulis* as a short compact organ, the internal walls of which are thrown into a series of ridges. A food-sorting caecum extends from the left posteriorly beneath the floor of the stomach and is connected by a deep groove with the opening of the mid-gut. Such a caecum is a much less complex structure than that of *C. virginica*. Leenhardt (1926 (17)) in describing *G. angulata* has followed the terminology of other authors such as Sabatier (1887 (27)) and Thiele (1886 (29)) for lamellibranchs, where the term "utricular stomach" corresponds to the anterior and posterior chambers of the stomach of *C. virginica*. He refers briefly to a "diverticulum stomach" which arises on the anterior, ventral surface of the utricular stomach and which probably is homologous with the caecum of *C. virginica*.

The internal surface of the anterior chamber of the stomach exhibits considerable irregularity and possesses numerous ridges. It is separated from the posterior chamber by a broad fold or ridge, which projects into the lumen (Fig. 6). This ridge is most prominent along the mid-ventral wall and would appear to serve as a means of directing food particles posteriorly through a narrowed channel.

An extensive area of the left ventral wall of the posterior chamber of the stomach is covered by a translucent gastric shield (Figs. 6 and 7). The latter consists of two main lobes or divisions which are joined by a narrow neck region. The anterior division is elliptical in outline and its shorter axis is directed anteroposteriorly. The posterior lobe is two to three times larger than the anterior lobe, and is roughly a quadrant with one radius serving as the ventral margin and the other radius as the anterior margin. The margins of the neck region, and the adjoining margins of both the anterior and posterior lobes are flexed, forming a clip arrangement which fits onto a corresponding elevation of the left wall of the stomach. The marginal flection extending along the anterior radius is considerably more prominent than the ventral one. The gastric shield bears a longitudinal crest or ridge which projects dorsally into the lumen of the stomach. It is most evident in the anterior lobe and becomes progressively reduced in the posterior lobe. The anterior lobe in addition bears a number of irregular prominences or teeth.



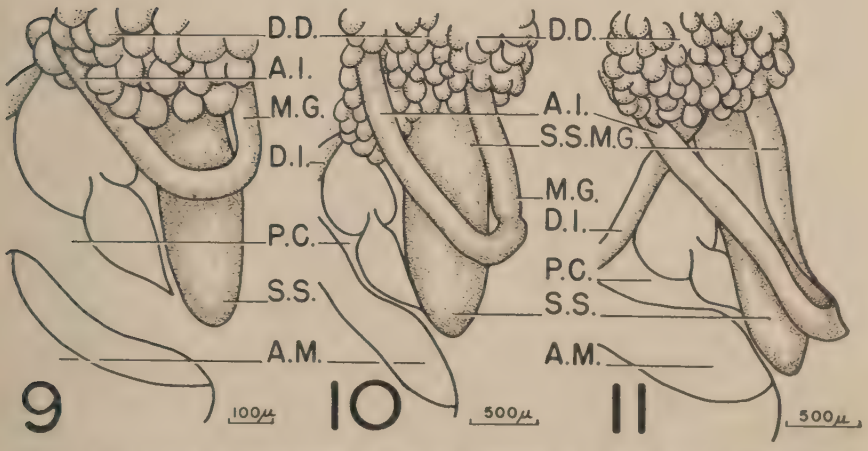


FIG. 8. Camera lucida drawing of cleared specimen of 3 mm. oyster spat viewed from right lateral aspect. A.I., ascending limb intestine; A.M.,S., adductor muscle, smooth; A.M.,ST., adductor muscle, striated; D.D., digestive diverticula; G.P., gill plates; H., heart; L.L.P., left labial palps; L.MA., left mantle; L.V., left valve; M., mouth; M.G., mid-gut; M.I., median limb intestine; R., rectum; R.L.P., right labial palp; S.S., style-sac.

FIGS. 9, 10, and 11. Camera lucida drawings showing relationship of style-sac and mid-gut of 3 mm., 7 mm., and 9 mm. oyster spat respectively, viewed from the right lateral aspect. A.I., ascending limb intestine; A.M., adductor muscle; D.D. digestive diverticula; D.I., descending limb intestine; M.G., mid-gut; P.C., pericardial cavity; S.S., style-sac; S.S.M.G., style-sac and mid-gut.

Nelson (1918 (22)) first coined the term "gastric shield" for the platelike structure of cartilaginous consistency at the point of contact between the anterior end of the style and the epithelium of the posterior stomach. For *C. virginica* he described it as a trilobular structure with the smallest of the three lobes concave on one surface forming a bowl-like depression possibly corresponding to the gastric clip arrangement as described here. The posterior lobe of the shield in the Malpeque Bay specimens is undivided, or marked only by a slight indentation of the posterior margin similar to that illustrated by Yonge (1926 (33)) for *O. edulis*.

Style-sac and Mid-gut

Just caudad to the gastric shield the posterior stomach leads into an elongated outpouching (Fig. 2), which occupies most of the ventral arm of the visceral mass. At the anterior end, two lateral valvular folds project into the lumen of the outpouching and continue posteriorly as the smaller or right and the larger or left typhlosoles, which incompletely divide the passageway into two parallel channels (Fig. 25). The mid-gut comprises the ventral channel and the style-sac lies somewhat dorsal to it. In cross section the lumen of the style-sac usually appears larger than that of the mid-gut, and irregularly circular to oval in outline in contrast to the somewhat laterally compressed mid-gut. Both typhlosoles show considerable variation, but the right one usually appears as a relatively low broad fold, while the left is somewhat more conical. These typhlosoles correspond to those of *O. chilensis* (Dahmen, 1923 (7)) and *O. edulis* (Yonge, 1926 (33)), but are somewhat less prominent than those of other lamellibranchs including *Anodonta* (Nelson, 1918 (22)), *Mya* (Edmondson, 1920 (8)), and *Ensis* (Graham, 1930 (13)). The lumina of the style-sac and the mid-gut enter a common posterior chamber at the mid-level of the adductor muscle.

Sabatier (1887 (27)) in describing *Mytilus edulis* first termed the style-sac and mid-gut a "tubular stomach". Purdie (1887 (25)) demonstrated that the "pyloric appendix" in *Mytilus latus* comprised the crystalline-style caecum and the direct intestine, which were partially separated by two overhanging longitudinal ridges. Dahmen (1923 (7)) referred to this portion of the tract in *O. chilensis* as a stomach intestine while Leenhardt (1926 (17)) using the term "estomac tubulaire" for *G. angulata* stated that it included a caecum or "canal cylindro-conique" separated from a parallel channel by two ridges. Nelson (1918 (22)) also described this region of the digestive tract for a number of lamellibranchs, including *C. virginica*, as consisting of two tubes incompletely separated by typhlosoles, and Yonge (1926 (33)) corroborated this for *O. edulis*.

The rodlike crystalline style is enclosed in the groove of the style-sac and extends forward to the surface of the gastric shield in the posterior chamber of the stomach. It is composed of gelatinous layers enclosing a central fluid (Fig. 22). The style was first described in detail for *C. virginica* by Nelson (1918 (22)) and does not appear to differ from that of *O. chilensis* (Dahmen, 1923 (7)), *O. edulis* (Yonge, 1926 (33)), or *G. angulata* (Leenhardt, 1926 (17).

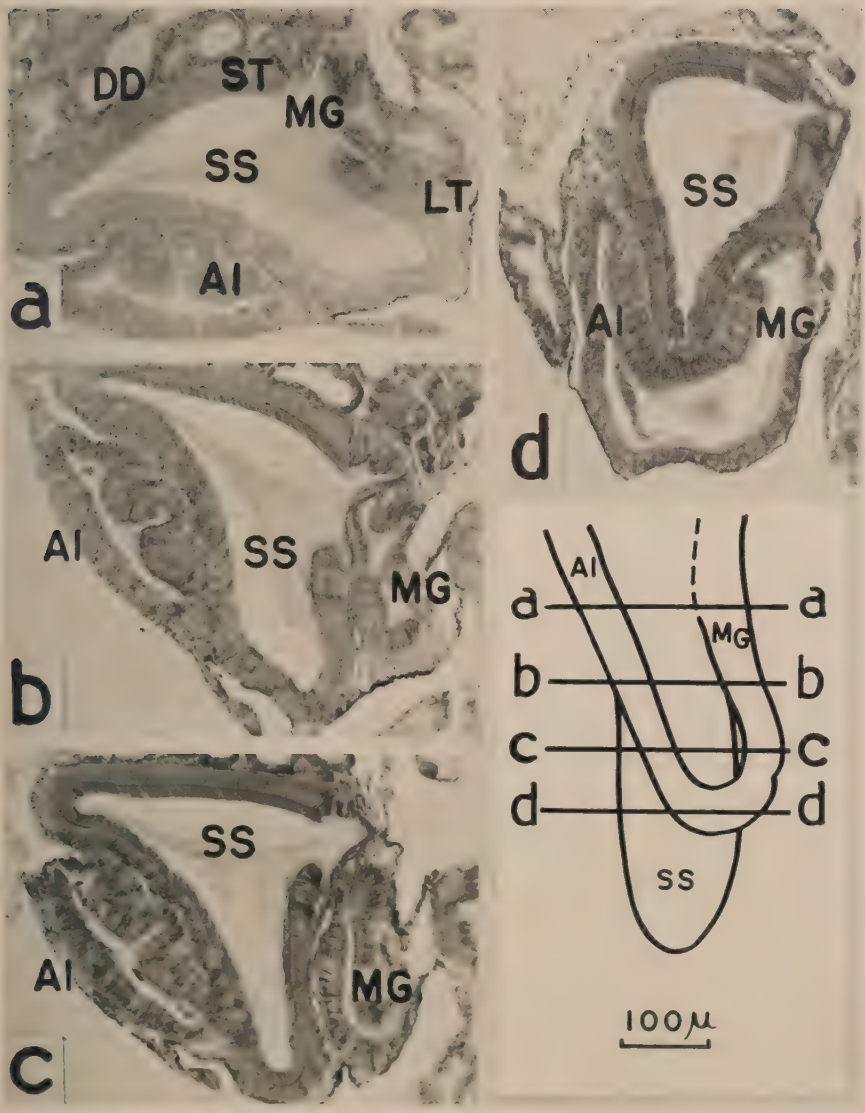


FIG. 12. Photomicrographs of cross sections of style-sac, mid-gut, and ascending limb of intestine of a 5 mm. oyster spat at levels as indicated by horizontal lines on diagrammatic outline. Alum cochineal and light green, 7 μ.

(*a*) Fused style-sac and mid-gut.

(*b*) Adjacent walls of style-sac and mid-gut degenerating prior to fusion.

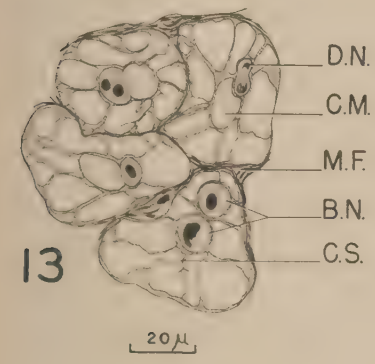
(*c*) Style-sac and mid-gut discreet, ventral wall of style-sac grooved and non-ciliated.

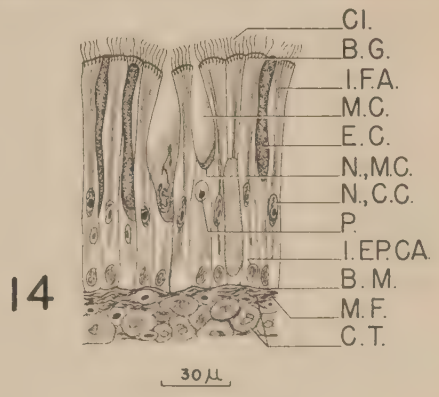
(*d*) Style-sac with mid-gut looping over right surface.

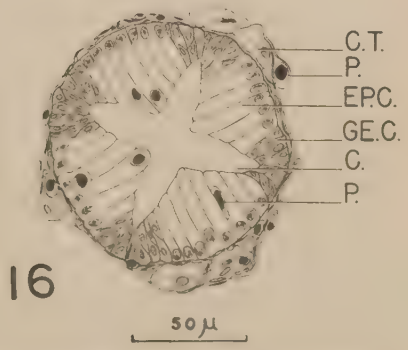
A.I., ascending limb intestine; D.D., digestive diverticula; L.T., larger typhlosole (left); M.G., mid-gut; S.S., style-sac; S.T., smaller typhlosole (right).

Intestine—Ascending, Median, and Descending Limbs and Rectum

From the common chamber at the posterior end of the style-sac and mid-gut the intestine can conveniently be divided into ascending or recurrent, median or vertical, and descending limbs, and the rectum. The ascending limb passes anteriorly by an abrupt flexure from its origin at the common posterior chamber of the style-sac and mid-gut (Fig. 3). It exhibits many variations in spatial relationship with reference to the style-sac and mid-gut. Most frequently it







Camera lucida drawings (semidiagrammatic) of histological sections of the digestive tract of *Crassostrea virginica*

FIG. 13. Typical Leydig cells or Langer's vesicles. B.N., binucleate cell; C.M., cytoplasmic mass; C.S., cytoplasmic strands; D.N., dividing nucleus; M.F., muscle fibers.

FIG. 14. Characteristic ciliated epithelium from style-sac. B.G., basal granule; B.M., basement membrane; Cl., cilia; C.T., connective tissue (collagenous fibers and Leydig cells); E.C., eosinophile; I.EP.CA., intraepithelial canal; I.F.A., intrafibrillar apparatus; M.C., mucous cell; M.F., smooth muscle fibers; N., C.C., nucleus of ciliated epithelial cell; N., M.C., nucleus of mucous cell; P., phagocyte.

FIG. 15. Transverse section of typical large duct of digestive diverticula. B.M., basement membrane; C.C., ciliated epithelial cell with heavy cuticular border (Cell Type 1); Cl., cilia; C.M.F., circular muscle fibers; C.T., connective tissue (collagenous fibers and Leydig cells); M.C., mucous cell; P., phagocyte.

FIG. 16. Transverse section of typical tubule of digestive diverticula. C., crypt; C.T., connective tissue; E.P.C., secretory (and absorptive) epithelial cell; GE.C., generative cell; P., phagocyte.

passes forward on the right ventral surface of the latter for some distance before flexing obliquely anterior to the pericardial cavity. Less frequently the flexure is more abrupt and it is parallel to the dorsal surface of the style-sac and mid-gut, and sometimes it forms the dorsal limb of a large U with the style-sac and mid-gut as the ventral limb. It subsequently follows the curvature of the dorsal surface of the ovoid visceral mass lying somewhat peripheral to the digestive diverticula.

The median or vertical limb of the intestine follows a crescentic course on the anterior surface of the ovoid visceral mass, passing to the left of the oesophagus. As the descending limb it curves posteriorly along the ventral surface of the ovoid visceral mass, and crossing obliquely to the left, anterior to the style-sac, mid-gut, and the ascending limb, it borders the dorsal margin of the pericardial sac. Aside from a slight decrease in diameter, the descending limb passes without gross demarcation into the rectum. The latter terminates dorsal to the smooth division of the adductor muscle to which it is firmly attached by connective tissue. Its posterior tip is mounted on a connective tissue papilla although the immediate anal region is free.

The course of the intestine is essentially similar to that of *O. chilensis* (Dahmen, 1930 (7)), *G. edulis* (Yonge, 1926 (33)), and *G. angulata* (Leenhardt, 1926 (17)) although it is apparently relatively longer and with less abrupt flexures than in the last species.

Digestive Diverticula

The digestive diverticula consist of irregular brownish-green lobules, which together with the oesophagus and stomach constitute the ovoid visceral mass. These lobules, bound together by an interlobular connective tissue stroma, are exposed on removal of the mantle. They consist of ducts and tubules which fill all the interspaces about the digestive tract proper.

The ducts by which the digestive diverticula communicate with the stomach occur in two main groups: the caecal ducts and the posterior gastric ducts. The caecal ducts may be conveniently divided into four groups (Figs. 4, 5), the most anterior of which represents the fusion of two large ducts. The apertures of these ducts are located along the anterior margin of the caecum. The posterior ducts, comprising two major groups, communicate with the posterior chamber of the stomach on the left side. Dahmen (1923 (7)) described six major ducts in *O. chilensis*, four of which open along the caecum, the remainder into the right and left sides of the stomach proper. Yonge (1926 (33)) indicated the presence of two large ducts opening on each side of the stomach in *O. edulis*, and Leenhardt (1926 (17)) found that several canals open into the "utriculaire" stomach in *G. angulata*.

Typhlosoles of the Intestine

At the posterior termination of the style-sac and mid-gut channels, the larger (left) and the smaller (right) typhlosoles (Fig. 25) unit into a single typhlosole with a median groove. This typhlosole, which comprises about one-half of the wall of the gut, continues tkroughout the remainder of the

digestive tract to within a short distance of the anus. In the ascending limb it is deeply grooved and occupies the left wall. With the flection of the intestine into the median limb it forms the anterior wall, while in the descending limb and rectum it comprises the right wall.

The external contours of the intestine and the surface of the typhlosole appear smooth and rounded when large quantities of food are present in the lumen. If there is little or no food or mucous, characteristic constrictions and dilatations in the opposite wall of the intestine are impinged on the typhlosole. These are evident throughout the entire tract with the exception of the anterior portion of the ascending limb and the median limb, both of which are somewhat deeply imbedded in the dense mass of the digestive diverticula.

Development of the Tract Following Setting

Development of the digestive tract in the larva of *C. Virginica* has been described by Brooks (1880 (4)), Stafford (1913 (28)), and Chestnut (1949 (5)). These descriptions, however, do not include accounts of the metamorphosis of the tract from the spat to the adult condition. The stomach is evident in early larval stages as an anterior enlargement of the semicircular tract. At the time of "setting" the style-sac is a blind posteriorly directed diverticulum of the stomach (Fig. 8). The mid-gut originates from the stomach slightly to the right and ventral to the base of the style-sac. It forms a loop on the right surface of the latter sac. The dorsal limb of the loop traverses the left surface of the stomach as the anlage of the ascending limb of the intestine. At the level of the base of the oesophagus it curves posteriorly, as the descending limb of the intestine and the rectum, to terminate on the dorsal surface of the adductor muscle. Subsequently the ventral wall of the style-sac and the closely approximating dorsal wall of the mid-gut become fused to one another (Figs. 9–12). This line of fusion is marked in the style-sac by a longitudinal groove of low sparsely ciliated epithelial cells. An initial thinning of the adjacent walls of both the style-sac and mid-gut is accompanied by a degeneration of the cilia and finally of the epithelial cells themselves, until only the basement membranes remain to be ruptured. This rupturing begins anteriorly and proceeds posteriorly. The smaller and larger typhlosoles extending the length of the style-sac and mid-gut are thus indicative of the right and left fused margins of the two channels. Fusion begins when the spat are between 3 and 5 mm. in length and appears to be complete in the majority of 10 mm. spat. The style-sac and mid-gut are thus a combined gastric and intestinal channel, as shown for *O. chilensis* (Dahmen, 1923 (7)) and for *O. edulis* by Yonge (1926 (33)) and Erdmann (1935 (10)), rather than simply a tubular stomach as Leenhardt (1926 (17)) has indicated in *G. angulata*.

Microscopic Anatomy of the Digestive Tract

The viscera of the oyster are bound together and supported by connective tissue consisting of Leydig cells alternately known as Langer's vesicles (Fig. 13), and delicate collagenous fibers. Leydig cells have been described for a

number of the molluscs (Bronn, 1935 (3)). In *C. virginica* (Fig. 13) they are multiangular and usually slightly elongated. Each cell possesses one or more vesicular nuclei which lie toward the periphery of a centrally-located mass of finely granular cytoplasm. Delicate cytoplasmic strands radiate from the central mass to the margin of the cell where they unite to form a thin border adjacent to the cell membrane. These cells are arranged at random except around blood vessels where the long axes radiate from the encircling collagenous fibers; and in the subepithelial and collagenous layers of the digestive tract and of the mantle. In the latter they form a circular layer with the long axes parallel to the lumen of the tract and the margin of the mantle respectively. Dahmen (1923 (7)) found the interspaces between the cytoplasmic strands to contain a clear fluid or very finely granular material. Bargeton (1941 (1)) indicated their importance in the storage of glycogen. In *C. virginica* these cells exhibit a seasonal variation in size. In early summer prior to spawning, they appear flattened, presumably owing to glycogen depletion and the pressure of the enlarging and permeating gonad. There is no marked change in the long axes, but the short axes are now reduced to from 20 to 40 μ. In late summer sometime after spawning, their long axes measure from 40 to 70 μ and their shorter axes from 35 to 60 μ.

The simple columnar epithelial lining layer of the digestive tract (Fig. 14) rests upon a homogenous basement membrane and is separated from the Leydig cell stroma by a somewhat dense, circularly arranged layer of delicate collagenous fibers. A few smooth muscle fibers, circularly and occasionally longitudinally disposed, usually permeate the periphery of the collagenous layer and partially or completely separate it from the underlying Leydig cells. The muscle fibres are sometimes fusiform, but occasionally appear to have blunt ends, a condition which may be partially attributed to the plane of section. The epithelium is ciliated throughout with the exception of the upper lip (fused external palps) where cilia are only sporadically present, the tubules of the digestive diverticula, and the lower side of the gastric shield in the posterior chamber of the stomach. The height of the epithelium varies from one region to another, as does the nature of the cilia. The cytoplasm is finely granular and the nuclei are large, oval in shape, and usually located from the middle to the base of the cell. The chromatin is sparse and tends to collect in coarse granules. One or more nucleoli are present near the nuclear membrane. An internal fibrillar apparatus appears to arise near the basement membrane in the form of elongated rods or fine fibrils. These fibrils converge as they pass toward the nucleus and thence spread in the form of a fan to merge into the basal granules near the free surface before penetrating the cuticle. There is considerable variation in the ease with which the internal fibrillar apparatus can be differentiated in different parts of the tract. Gutheil (1911 (15), 1912 (16)) described this apparatus in *Anodonta cellensis*, but did not observe it basal to the nucleus although Ellermann (1899 (9)) suggested that the fibrils extended toward the bases of the epithelial cells in the snail *Helix pomatia*. Mackintosh (1925 (20))

has indicated a similar internal fibrillar apparatus in *Crepidula fornicata* as has Yonge (1926 (33)) for *O. edulis*, and Leenhardt (1926 (17)) for *G. angulata*. A series of "intra-epithelial" canals in the basal third of the cells are similar to those demonstrated by Mackintosh (1925 (20)) and Yonge (1926 (33)). It is suggested that these canals lend tensile strength to the epithelium since they are filled with a densely-staining stringy or albuminous substance and penetrate the bases of the cells.

Secretory epithelial cells of the goblet type are interspersed amongst the ciliated cells. Their proportions and numbers vary from one region of the tract to another (Fig. 14). Some of these are actively secreting mucous cells, while others are apparently regenerating cells. Coarsely vesicular mucous granules or droplets are grouped as ovoid to spindle-shaped masses which extend variable distances from the free border toward the bases of the cells. The granules stain weakly with basic dyes although in early stages before taking on a vesicular character, they stain more intensely. The densely-staining nucleus is oval or crescentic in shape depending upon the volume of secretion. It is located in a position somewhat eccentric to the basal margin of the ovoid mass of secretion. The cytoplasm is finely granular and similar to that of the ciliated cells. Leenhardt (1926 (17)) first described the so-called eosinophilic cell in *G. angulata*. It is an elongated cell, laden with coarse granules, which may extend throughout most of the length of the cell, and cause it to be distended to a greater or lesser extent especially toward the free margin. Cells of this type can be recognized in the digestive epithelium of *C. virginica*. The granules can be stained with both iron and acid hematoxylin and also intensely with acid dyes, such as eosin. The densely-staining nucleus is spherical or oval in shape and located in finely granular cytoplasm toward the base of the cell. Nelson (1955 (24)) has suggested that these may represent a secretory phase of the mucous cell. Validity is loaned to this hypothesis in that there is sometimes considerable difficulty in distinguishing these cells from mucous cells, and wherever mucous cells are abundant, eosinophiles are sparsely represented. Dahmen (1923 (7)) and Yonge (1926 (33)) for *O. chilensis* and *O. edulis* respectively refer to only one type of secretory cell, the "mucous" gland, which occurs in various regions of the digestive tract. The nuclei appear to be identical with those of the ciliated cells. They fail to distinguish any cells which correspond to the eosinophiles of *G. angulata* (Leenhardt, 1926 (17)).

Wandering phagocytic cells from 7 to 10 μ in diameter occur in variable numbers in the lumen, among the epithelial cells and in the surrounding connective tissues of the entire digestive tract. Their small spherical nuclei are 4 to 5 μ in diameter and the chromatin occurs as fine densely-staining granules. The cytoplasm stains faintly with acid dyes. In fixed preparations they frequently exhibit numerous blunt pseudopodia. Some investigators refer to these cells as amoeboid cells or amoebocytes (Yonge, 1926 (33)), while others term them leucocytes (Mackin, 1951 (19)). Gutheil (1912 (16)) showed for *Anodonta* and Yonge (1923 (31)) for *Mya* sp. that large particles

of food can be phagocytized by them and hence they may play an important role in assimilation.

Table I gives a résumé of the specific characteristics of the lining epithelium and extraepithelial tunics of the digestive tract of *C. virginica*. The following descriptions will accordingly deal largely with certain distinguishing features of the various regions.

Labial Palps (Figs. 17, 18)

Each fleshy labial palp is composed of a core of connective tissue surmounted by simple columnar epithelium resting on a homogeneous basement membrane. The connective tissue consists of Leydig cells with some collagenous fibers, the latter, along with longitudinally arranged smooth muscle fibers, being largely concentrated as a layer beneath the basement membrane. The smooth surfaces of the palps, i.e. the lateral faces of the external palps and the medial faces of the internal palps, are bordered by a sparsely ciliated low columnar epithelium with or without a thin cuticle. Both mucous and eosinophilic cells may be interspersed amongst the ciliated cells. The adjacent surfaces of both pairs of palps bear prominent transverse ridges or flutings separated by grooves, and are covered by a heavily ciliated tall columnar epithelium with a distinct cuticle. In longitudinal sections the ridges present an oblique appearance, the proximal walls usually being straight, while the distal walls are characterized by shallow grooves, as Leenhardt (1926 (17)) illustrated for *G. angulata*. Mucous cells tend to be more concentrated at the bases of the furrows and become progressively reduced in numbers toward the summits of the folds. Yonge (1926 (33)) has shown in *O. edulis*, however, that unicellular mucous glands are almost exclusively confined to the vicinity of the summits of the folds. Phagocytes between the epithelial cells and longitudinally arranged muscle fibers under the epithelium of the furrows are also present in *O. edulis*.

Mouth Cavity and Oesophagus (Figs. 19, 20, 30)

In the region of the upper lip formed by the fused external palps the epithelium is low columnar and non-ciliated or irregularly ciliated. The free surfaces of many of the cells bear irregular, rounded, cytoplasmic projections. Most of the cells are of the mucous type, but interspersed among them are prominent eosinophilic cells. The epithelium rests upon a basement membrane which in turn is separated from the adjacent Leydig cells by a layer of collagenous fibers through which are interspersed a few longitudinally arranged smooth muscle cells. The ciliated epithelium forming the covering of the lower lip (fused internal palps) and the lining of the oral cavity is tall columnar with cilia decreasing in length from the entrance toward the oesophagus. Mucous cells are prominent, but are never distended to the extent of those of the upper lip. Dahmen (1923 (7)) found in *O. chilensis* that the mouth opening and oesophagus show a tall, cuticulated epithelium, upon which cilia could be demonstrated in only a few instances. Yonge (1926 (33)) observed that the epithelium of the mouth of *O. edulis* is continuous with

TABLE I

HISTOLOGICAL CHARACTERISTICS OF THE DIGESTIVE TRACT OF *Crassostrea virginica* (GMELIN)

(from specimens 8–10 cm. in length)

	Epithelium						Extraepithelial tunics		
Division of tract	Height of cell, μ	Length of cilia, μ	Cuticle	Mucous cells	Eosinophilic cells	Phagocytes	Basement membrane	Collag. conn. tissue	Smooth muscle
Palps									
Ridged surface	40–50	10–15	+	++	+	+	+	+	+
Smooth surface	20–30	5–7	±	+	+	+	+	+	+
Mouth									
Upper lip (fused external palps)	25–30	0–10	+	++	+	+	+	+	+
Lower lip (fused internal palps)	50–55	15–25	+	++	−	+	+	+	+
Roof	50–55	10–20	+	+	−	+	+	+	+
Floor	50–55	10–20	+	++	−	+	+	+	+
Oesophagus	75–105	10–15	+	++	+	+	+	+	+
Stomach									
Anterior chamber	55–180	15–20	+	+	−	+++	+	+	+
Caecum	20–155	7–15	+	+	−	+	+	+	+
Posterior chamber	45–180	15–25	+	+	−	+	+	+	+
Gastric shield region	50–230	−	+	−	−	++++	+	+	+
Style-sac, Mid-gut									
Style-sac	65–150	7–25	+	++	+	++	+	+	+
Mid-gut	55–160	5–20	+	+++	+	++++	+	+	+
Intestine									
Ascending limb	85–130	5–20	+	+	+++	++	+	+	+
Median limb	65–115	5–12	+	++	+	++	+	+	+
Descending limb	75–110	7–15	+	+++	+	++++	+	+	+
Rectum	50–125	15–25	+	+++++	+	+++	+	+	+
Anus	90	10	+	+++	+	++++	+	+	+
Digestive diverticula									
Ducts									
Large caecal and gastric									
Cell Type I	15–25	8–10	++	++	+	++	+	+	+
Cell Type II	25–40	4–8	+	++	+	++	+	+	+
Pretubular	10–25	4–6	+	+	+	+	+	+	+
Tubules									
Secretory cells	10–35	−	−	−	−	+	−	+	??
Generative cells	5–15	−	−	−	−	+	−	+	

NOTE: + signs indicate presence and relative frequency.

that of the grooves between the palps and consists of long, ciliated cells with a few mucous glands, as did Leenhardt (1926 (17)) for *G. angulata.*

The epithelium of the oesophagus is tall, has a prominent cuticle, and bears heavy relatively short cilia, as in *G. angulata* (Leenhardt, 1926 (17)). Mucous cells are numerous and become more abundant toward the stomach, but eosinophilic cells are few. The basement membrane is heavy and lies on a distinct band of collagenous fibers containing a few strands of circularly and longitudinally arranged muscle cells. Phagocytes are scattered throughout the epithelium. Prominent folds may occur in the lateral margins of the oesophagus, which presumably would permit expansion during the passage of food to the stomach. Dahmen (1923 (7)) indicated a high, ciliated epithelium with some mucous cells for *O. chilensis*, as did Yonge (1926 (33)) for *O. edulis* where, however, phagocytes are numerous and "mucous" glands fewer.

Stomach (Figs. 21, 22, 32–34)

The internal surface of the stomach is thrown into irregular ridges separated by furrows. Epithelial cells covering the ridges are much taller than those lining the furrows, and such differences in height partially account for the irregular character of the lumen. With the exception of the gastric shield area of the posterior chamber, the entire epithelial lining is ciliated. Some mucous cells are present but few, if any, eosinophilic cells. In the caecum the epithelium progressively decreases in height from the point of exit from the anterior chamber to the blind terminations of the appendices, with the length of the cilia being correspondingly reduced. Phagocytes are present in large numbers below the prominent basement membrane, between the epithelial cells, and in the lumen. A few smooth muscle cells are arranged irregularly in both a longitudinal and circular direction to form, with collagenous fibers, an extraepithelial tunic. The gastric shield region appears in transverse section to be shaped like an arrowhead (Figs. 22, 23, 24). The epithelium resembles that of the other regions of the stomach except for the apparent lack of cilia. Fine cytoplasmic processes arising from the free borders of some of the cells unite with the overhanging gastric shield and are suggestive of degenerate or modified cilia (Fig. 35). The cells at the apex of the arrowhead (Fig. 36) are very tall, reaching a height of 230 μ, but taper laterally where they become continuous with the cellular lining of the adjacent posterior chamber. The nuclei are slender and situated somewhat nearer the basement membrane than in other regions of the stomach. Neither mucous nor eosinophilic cells appear to be present but numerous phagocytes occur between the epithelial cells. The histological structure of the stomach wall closely resembles that of other described species, *O. chilensis* (Dahmen, 1923 (7)), *G. angulata* (Leenhardt, 1926 (17)), and *O. edulis* (Yonge, 1926 (33)).

The gastric shield is composed of homogeneous layers of a chondroid-like substance (Nelson, 1918 (22)), which stains intensely with acid dyes. The laminated character is most readily exhibited in sections at the apex of the crest or ridge (Figs. 23, 24). The laminae gradually decrease in thickness from the apex to the margins of the shield. The hyaline gastric shields of

Mytilus (List, 1902 (18)) and of *Anodonta* (Gutheil, 1911 (15)) are formed by the fusion of droplets of secretion from the underlying epithelial cells. Although Yonge (1926 (33)) could find no evidence of such secretion in *O. edulis*, nevertheless the shield is joined to the epithelium by fine strands which pass through it and have the appearance of abortive fused cilia arising from basal granules. In *C. virginica*, as indicated above, there are evidences of cytoplasmic connections between the shield and the underlying epithelium and although, during the preparations of sections, such processes are usually severed near the apex, they can be demonstrated near the margins. Dahmen (1923 (7)) and Leenhardt (1926 (17)) consider the gastric shields of *O. chilensis* and *G. angulata* respectively to be products of cellular secretions which have filtered across the border of the epithelial cells to be incorporated with the cilia. The gastric shield could be analogous in certain respects to the peritrophic membrane of insects, which Wigglesworth (1950 (30)) has shown is in some instances composed of concentric lamellae secreted by the underlying epithelial cells of the mid-gut. It may be postulated, therefore, that if the gastric shield of the oyster is chiefly secreted by the epithelial cells beneath the apex, the chondrin would flow laterally, becoming attached to the cilia, which subsequently degenerate. Such a suggestion might account for the failure to observe any central attachment of the shield to the underlying epithelium, whereas the thinner margins invariably adhere by cytoplasmic processes.

Style-sac and Mid-gut (Figs. 25, 37, 38, 39)

The most striking feature of the epithelium lining the style-sac is the density and uniformity of the cilia in contrast to those found in any other region of the digestive tract. The cells are very regularly arranged with large ovoid nuclei. The internal fibrillar apparatus is more prominent than in any other part of the tract. The epithelium comprising the mid-gut wall varies considerably in height and the cilia lack the regularity of arrangement of those in the adjoining style-sac. Phagocytes and mucous cells are somewhat more numerous in the mid-gut wall than in that of the style-sac, (Table I) but eosinophilic cells are sparsely represented in both. In both style-sac and mid-gut the basement membrane is surrounded by a layer of collagenous fibers with sparsely interspersed circularly arranged smooth muscle fibers. Dahmen (1923 (7)), Yonge (1926 (33)), and Leenhardt (1926 (17)) describe no muscle cells around the epithelium in *O. chilensis*, *O. edulis*, and *G. angulata*, but otherwise this division of the tract appears to be essentially the same in these species.

The typhlosoles consist of a core of Leydig cells covered by tall, columnar epithelial cells which grade on one side into those of the style-sac, and on the other into those of the mid-gut. However, the transition from the epithelium of the style-sac to that of the mid-gut is much more abrupt for the smaller or right typhlosole than for the larger or left one and is usually marked by a cleft. The cilia of the smaller typhlosole approximate those of the style-sac in length measuring up to 20 μ while those of the larger typhlosole

range from 10 to 15 μ. Mucous cells are usually more abundant on the larger typhlosole.

The lumen of the style-sac is occupied by a gelatinous white to yellowish-brown rod, the crystalline style, whose anterior end extends into the posterior chamber of the stomach to rest against the gastric shield. The central core is fluid while the periphery is firm and consists of several gelatinous strata. In fixed specimens the style usually disintegrates, but occasionally its outer layers may be identified in sections (Figs. 22, 34). There are diverse opinions regarding the origin of the acellular crystalline style in lamellibranchs. Its formation has been attributed to the secretory activity of the walls of the "caecum" (Barrois, 1889 (2)) and the "liver" (Mitra, 1901 (21)). Although many investigators (List, 1902 (18); Nelson, 1918 (22); Edmondson, 1920 (8); Mackintosh, 1925 (20); Graham, 1930 (13)) have suggested that it is secreted by the narrow cells of the minor or right typhlosole, none have been able to offer authentic evidence. Gutheil (1912 (16)) has described clear secretory granules above the nuclei in the ciliated cells of the style-sac of *Anodonta cellensis*. Yonge (1926 (32)) demonstrated the presence of droplets of secretion in the style-sac epithelium of part of the minor typhlosole of both *Mytilus edulis* and of *O. edulis* after the injection of iron saccharate, and concluded that these cells of the groove of the style-sac are instrumental in the formation of the style. Leenhardt (1926 (17)) observed certain haematoxylin-staining granules in the style-sac ("caecum") of *G. angulata* to which he attributed the secretion of the crystalline style. There has been no evidence of such specifically staining granules in the epithelium of the style-sac of *C. virginica*.

Intestine—Ascending, Median, and Descending Limbs (Figs. 25, 26, 41, 42)

The intestine is characterized by a prominent typhlosole with a median groove. The narrow lumen has the form of a double crescent when observed in transverse section. The epithelial lining exhibits great uniformity throughout all three limbs, the ciliated cells resembling those of the mid-gut adjoining the style-sac. Mucous cells and eosinophilic cells are both present, with the former increasing in abundance along the course of the tract (Table 1). Phagocytes are numerous among the epithelial cells, below the basement membrane, as well as in the lumen of the tract. The basement membrane of the ascending limb is very broad, but becomes progressively less pronounced as the intestine grades into the rectum. It rests upon a thin layer of collagenous fibres among which are occasionally interspersed a few smooth muscle fibers, most of which are circularly arranged.

The typhlosole consists of a more or less V-shaped mass of Leydig cells surmounted by epithelial cells which are tallest on either side of the median groove, and becomes lowest at the base of the groove. On the opposite wall of the gut, the epithelium in the mid-line may project into the median groove of the typhlosole.

Morphologically and histologically, the intestine resembles that described by Dahmen (1923 (7)) for *O. chilensis* and by Yonge (1926 (33)) for *O. edulis* except that in these species muscular tissue has not been demonstrated. Field (1922 (11)) describes circularly arranged muscle fibers in the intestine of *Mytilus edulis* while Leenhardt (1926 (17)) illustrates for *G. angulata* an epithelium comparable to that of *C. virginica*, but does not refer to any muscular cells although the connective tissue layer is prominent. He is in agreement with Sabatier (1887 (27)), who suggested that the connective tissue layer of the intestine of *Mytilus edulis* could be considered as a lymphoid organ because of the large number of amoebocytes present. Such a condition may also hold true for *C. virginica* since these cells are abundant in this region of the tract.

Rectum (Figs. 27, 28, 43, 44)

The rectum resembles the preceding limbs of the intestine with the exception that the typhlosole is more pronounced and the median groove correspondingly deeper. Numerous epithelial folds occur in the lateral walls of the rectum while coarser folds appear in the adjacent typhlosole. The typhlosole gradually disappears near the anal region when the tract assumes a more or less circular outline. Its internal surface is thrown into small folds.

There is a marked increase in the numbers of mucous cells progressively from the median limb of the intestine toward the rectum and anus. Sometimes they may even predominate in numbers over the ciliated cells. Relatively few eosinophilic cells occur in either the rectum or the anal region. Phagocytic cells are numerous throughout the epithelium and beneath the thin basement membrane. There is a definite layer of smooth muscle fibers, circularly arranged, in the region of the anus. Leenhardt (1926 (17)) noted smooth muscle fibers in *G. angulata* which became sufficiently abundant in the anal region as to form a sphincter, but neither Dahmen (1923 (7)) nor Yonge (1926 (33)) refer to them in *O. chilensis* and *O. edulis*.

Digestive Diverticula (Figs. 15, 16, 29, 45, 46, 47)

The digestive diverticula in the oyster are organs of absorption and of intracellular digestion (Yonge, 1926 (32)). The tubules and the ducts of these diverticula are grouped in the form of small lobules indistinctly separated and bound together by interlobular connective tissue composed of Leydig cells with some collagenous fibers. The histological structure of the larger ducts which communicate directly with the caecum and the posterior stomach generally resembles the adjacent region of the stomach. The lumina sometimes appear circular in outline, at other times crescentic or often multiangular. As the primary ducts branch leading toward the secretory tubules, a difference in the height and character of the ciliated epithelium occurs on opposite sides of the wall. On one side the cells are somewhat short and broad with lightly staining nuclei (Cell Type I, Table I). There is a heavy cuticular border and the cilia are relatively long and dense. Cells on the opposite side may be almost double in height, the cuticle is thin, and the cilia

somewhat shorter (Cell Type II, Table I.). Mucous cells are much more profuse among the elongated ciliated cells, and eosinophilic cells occasionally occur. The lumina of the immediate pretubular ducts are generally circular in outline and the epithelial cells become progressively uniform in height. Phagocytes are present in the epithelium, in the lumina, and in the surrounding connective tissue. Circularly arranged smooth muscle fibres imbedded in collagenous connective tissue surround the basement membrane. The structure of the duct resembles that described by List (1902 (18)) and Field (1922 (11)) for the "liver canals" of the digestive diverticula of *Mytilus edulis*. Dahmen (1923 (7)) and Yonge (1926 (33)) observed no special variation in the epithelium of the ducts from that of the stomach for *O. chilensis* and *O. edulis* respectively, but Leenhardt (1926 (17)) recorded an arrangement for *G. angulata* which is similar to that observed here in C. *virginica*.

The histological structure of the secretory units of the digestive diverticula is quite different from that of the ducts and a seasonal variation is exhibited. Yonge (1926 (32)) has described the units as tubules for a large number of lamellibranchs including *O. edulis*, as did Dahmen (1923 (7)) for *O. chilensis*, while Leenhardt (1926 (17)) has considered them to be in the form of acini in *G. angulata*. Graphic reconstruction of the units from serial sections indicates their tubular rather than their acinar character in *C. virginica*. During the spring and summer months when the lining epithelium is tall, the lumina of the tubules appear roughly in the form of a cross or H and less frequently tripartite. The non-ciliated epithelium comprising the wall is of two types. Generative cells located in the crypts formed by the extremities of the cross are small with large nuclei, each of which possesses a nucleolus. The cytoplasm is somewhat granular and darkly-staining and a basement membrane is not evident. Both Yonge (1926 (32)) and Leenhardt (1926 (17)) consider that these cells are capable of replenishing the absorptive and secretory cells of the remainder of the tubule. Cells of the latter type progressively increase in height from the crypt toward the central lumen and rest on a basement membrane. The cytoplasm is coarsely vacuolated and stains very lightly in comparison with that of the generative cells. Sometimes engulfed food particles are evident. Phagocytes may be present among the epithelial cells. A thin layer of collagenous connective tissue surrounds each tubule. During the winter season (Fig. 47) the lumina of the majority of the tubules become spherical or somewhat ovoid in outline. The peripheral borders of the large coarsely vacuolated cells are quite irregular and some exhibit extensive degeneration. There appears to be no change in the generative cells which occur at the angles of the crypts.

Acknowledgments

The authors wish to express their appreciation to the Fisheries Research Board of Canada for the supply of oysters and for financial aid in support of this investigation; to Mr. R. R. Logie, Fisheries Research Board, Biological Station at Ellerslie, P.E.I., for his interest and help at all times; to

Dr. T. C. Nelson, Rutgers University, for his critical reading of the manuscript; and to Mr. Charles Jarvis, Dapartment of Microscopic Anatomy, for the photomicrography.

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FIGS. 17–29. Photomicrographs of histological sections of the digestive tract of *Crassostrea virginica*.

FIG. 17. Longitudinal section of the adjacent ridged medial surface of an outer labial palp, and the lateral surface of an inner labial palp. Ehrlich's haematoxylin and Triosin, 10 μ. ×50.

FIG. 18. Longitudinal section of a ridge and adjacent furrows of the lateral surface of an inner labial palp showing the almost straight proximal wall and the grooved distal wall. Ehrlich's haematoxylin and Triosin, 10 μ. ×300.

FIG. 19. Sagittal section showing the relationships of the labial palps, mouth cavity, and oesophagus. Mallory's triple stain, 10 μ. ×12.

D.D., digestive diverticula; I.P., inner palp; M., mouth cavity; O., oesophagus; O.P., outer palps.

FIG. 20. Sagittal section of oral cavity showing low non-ciliated and sparsely ciliated epithelium of upper lip (fused external palps) merging into the typical ciliated columnar epithelium on the roof and floor (right). Mallory's triple stain, 10 μ. ×85.

FIG. 21. Slightly oblique transverse section of stomach region of 5 mm. oyster spat. A.S., anterior chamber of stomach; C., caecum; D.D., digestive diverticula; P.S., posterior stomach. Alum cochineal and light green. ×100.

FIG. 22. Coronal section through the stomach. ×12.

A.S., anterior chamber of stomach; C., caecum and (anterior appendix); C.S., crystalline style; D.D., digestive diverticula; G.S., gastric shield; P.S., posterior stomach. Ehrlich's haematoxylin and Triosin.

FIG. 23. Posterior chamber of stomach showing cliplike attachment of gastric shield to underlying epithelium. Ehrlich's haematoxylin and Triosin, 10 μ. ×33.

FIG. 24. Enlarged view of Fig. 23 showing the laminated character of the gastric shield. ×150.

FIG. 25. Cross section of the style-sac and mid-gut, and ascending limb of intestine. Ehrlich's haematoxylin and Triosin, 10 μ. ×20.

A.I., ascending limb of intestine; M.G., mid-gut; S.S., style-sac; L.T., larger or left typhlosole; S.T., smaller or right typhlosole.

FIG. 26. Transverse section of the descending limb of the intestine showing the prominent typhlosole with the median groove. Van Gieson's and light green, 10 μ. ×20.

FIG. 27. Transverse section of the rectum showing pronounced grooved typhlosole. Ehrlich's haematoxylin and Triosin, 10 μ. ×25.

FIG. 28. Transverse section of preanal rectum; the typhlosole is disappearing, epithelial folds are present. Ehrlich's haematoxylin and Triosin. ×35.

FIG. 29. Portion of an extensively branched caecal duct of the digestive diverticula with sections of adjacent tubules. Ehrlich's haematoxylin and Triosin, 10 μ. ×70.

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Shaw and Battle—Can J. Zool.

FIGS. 30–47. Photomicrographs of histological sections of the digestive tract of *Crassostrea virginica*.

FIG. 30. Non-ciliated and sparsely ciliated epithelium of the upper lip (fused external palps). Mallory's triple stain, 10 μ. ×600.

E.C., eosinophilic cell; L.C., Leydig cell; M.C., mucous cell; P., phagocyte or leucocyte.

FIG. 31. Ciliated epithelial lining of oesophagus. Ehrlich's haematoxylin and Triosin, 7 μ. ×450.

One prominent eosinophilic cell is evident, also numerous mucous cells and phagocytes.

FIG. 32. Wall of the anterior chamber of stomach. Ehrlich's haematoxylin and Triosin, 10 μ. ×250.

The ciliated cells have a prominent cuticular border. Mucous cells are abundant and phagocytes occur in the lumen and throughout the epithelium and underlying layers.

FIG. 33. Mid-region of the anterior appendix of the caecum. Ehrlich's haematoxylin and Triosin, 10 μ. ×250.

FIG. 34. Wall of the posterior chamber of stomach. Ehrlich's haematoxylin and Triosin, 10 μ. ×225.

Phagocytes are numerous throughout the epithelium. The cilia are long and the cuticular border is prominent. Mucous cells are abundant. C.S., crystalline style.

FIG. 35. Wall of the posterior chamber of stomach immediately under the apex (neck) of the gastric shield (G.S.). Ehrlich's haematoxylin and Triosin, 10 μ. ×225.

The gastric shield has separated from the surface of the epithelial cells during sectioning. The non-ciliated epithelial cells are the maximum height for the digestive tract.

FIG. 36. Marginal area of the gastric shield showing the cytoplasmic processes of attachment to the peripheral borders of the cells. Iron haematoxylin and light green, 7 μ. ×500.

FIG. 37. Junction of style-sac and mid-gut. Ehrlich's haematoxyli nand Triosin, 10 μ. ×75.

L.T., larger or left typhlosole; M.G., mid-gut; S.S., style-sac; S.T., smaller or right typhlosole.

FIG. 38. Enlarged view of style-sac on right and adjoining smaller typhlosole of mid-gut on left. ×225.

FIG. 39. Longitudinal section through the style-sac showing uniformity of heavily ciliated surface. Few phagocytes are present. Ehrlich's haematoxylin and Triosin, 10 μ. ×200.

FIG. 40. Typical ciliated epithelium of the style-sac showing internal fibrillar apparatus. Cresyl echt violet, 7 μ. ×500.

FIG. 41. Longitudinal section through the mid-gut showing ciliated epithelial cells and abundant phagocytes. Ehrlich's haematoxylin and Triosin, 10 μ. ×200.

FIG. 42. Transverse section of the ciliated epithelial lining of the ascending limb of intestine. Ehrlich's haematoxylin and Triosin, 7 μ. ×225.

Eosinophilic cells are darkly stained. Mucous cells and phagocytes are numerous.

FIG. 43. Cross section through the ciliated epithelial lining of the lateral wall and adjacent typhlosole of the rectum. Phagocytes are present in large numbers. Ehrlich's haematoxylin and Triosin, 7 μ. ×225.

FIG. 44. Coronal section of ciliated epithelial surface of the anal region, showing prominent mucous cells and infiltration of phagocytes. Ehrlich's haematoxylin and Triosin, 10 μ. ×225.

FIG. 45. Transverse section of a large duct of the digestive diverticula with some degenerating tubules from a specimen fixed during the early winter (late November). Ehrlich's haematoxylin and Triosin, 10 μ. ×70.

Mucous cells interspersed among the ciliated epithelial cells are abundant in the upper two-thirds of the duct but are rare in the lower third where the cuticle is heavy.

FIG. 46. Typical tubules of the digestive diverticula with large lightly-staining vacuolated secretory and absorptive cells, and small darkly-staining generative cells. A section of a small duct to the upper left. Ehrlich's haematoxylin and Triosin, 10 μ. ×275.

FIG. 47. Typical tubules of the digestive diverticula during the winter season, showing the degeneration of the free border of the vacuolated secretory cells. Ehrlich's haematoxylin and Triosin, 10 μ. ×275.

THE HETEROGENEITY OF OSTREASTEROL AND CHALINASTEROL

SIR,—Since 1934 several attempts have been made to assign a chemical structure to "ostreasterol" isolated from the Atlantic oyster *Crassostrea virginica*.[1-4] It has been suggested that it is identical to "chalinasterol" isolated from several sponges and assigned the structure $\Delta^{5,22}$-campestadien-3β-ol.[4]

The sterols of the Pacific oyster *Ostrea gigas* have been shown to be difficultly separable by chromatography of the *p*-phenylazobenzoyl esters into four component sterols. The major component (36%) has been shown to be 24-methylenecholesterol both by degradation and synthesis. Another component (30%) has only one double bond. A third sterol (29%) has two double bonds and a fourth (5%) has a conjugated diene structure.[5-6]

Recently it has been shown that the infrared spectrum of "ostreasterol" is identical to "chalinasterol" and on the assumption that "ostreasterol" therefore has the structure $\Delta^{5,22}$-campestadien-3β-ol it is suggested that either this is a case where the *trans* double bond does not absorb at 970 cm.$^{-1}$ or alternatively that "ostreasterol" is the *cis* isomer.[7] Both these conclusions presuppose that "ostreasterol" is a single chemical entity. However, in spite of the demonstrated heterogeneity of the sterols from the Pacific oyster, no attempt was made to subject "ostreasterol" from the Atlantic oyster to a similar chromatographic study before concluding that it is a single chemical entity. Indeed, the published infrared spectra of "ostreasterol" and "chalinasterol" show that both are heavily contaminated (*ca* 30-50%) with a sterol containing a terminal methylene group. Both spectra are qualitatively identical to the sterol mixture from the Pacific oyster and show the absorption at 885 and 1640 cm.$^{-1}$ previously shown for 24-methylenecholesterol from the Pacific oyster. We must conclude that neither "ostreasterol" nor "chalinasterol" is a single chemical entity, and further conclusions on the component sterols of the oyster, other than 24-methylenecholesterol, should be made cautiously until these sterols are available in a pure state.

I am, Sir, etc.,

D. R. IDLER
U. H. M. FAGERLUND

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2 Bergmann, *ibid.*, 1934, **104**, 553
3 Bergmann, Schedl & Low, *J. org. Chem.*, 1945, **10**, 587
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Chemistry and Industry, April 6, 1957, page 432.

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A NEW ADENYL-SUCCINIC ACID DERIVATIVE CONTAINING SULFATE AND A PEPTIDE[1]

Sir:

Recently, the occurrence of adenine-succinic acid and adenyl-succinic acid has been reported from several laboratories. Yeast,[2] *Escherichia coli*,[3] mammalian liver[4] and cod liver[5] have been demonstrated to contain one or both of these compounds. In the present communication the authors wish to report the isolation and identification of a derivative of adenylsuccinic acid (I) from salmon liver.

The livers were excised from live spring (king) salmon at sea and immediately frozen in dry ice. The acid soluble phosphorus compounds were extracted into cold perchloric acid and chromatographed on Dowex-1 anion exchange resin exactly as previously described except that a refrigerated column and fraction collector were used.[6] The fraction under consideration (E) appeared immediately after adenosine diphosphate from the ion exchange column in a formic acid system (Fig. 1). Fraction E was separable into three components

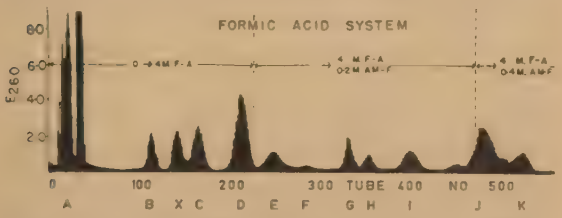

Fig. 1.—Gradient elution of nucleotides on a 1.0 × 20 cm. bed of Dowex-1 formate resin at 0°. The mixing volume was 500 ml. and 5-ml. fractions were collected.[6]

(E_1, E_2 and E_3) by paper chromatography (Table I). Compound I (E_2) moved centrally in relation to the other two and generally comprises approximately 80% of the fraction. It behaved as a single entity on several paper chromatograms (Pabst solvents 1, 2 and 3) and was electrophoretically homogeneous at several *p*H's. Compound I has an

(1) Presented in part at the 130th Meeting of the American Chemical Society, Atlantic City, September, 1956, but not abstracted.
(2) C. E. Carter and L. H. Cohen, THIS JOURNAL, **77**, 499 (1955).
(3) I. Lieberman, *ibid.*, **78**, 251 (1956).
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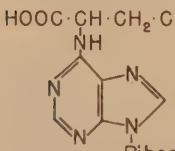
absorption maximum of 266 mμ in acid and gives positive tests for phosphate, sulfate and ribose, and a positive ninhydrin reaction. Analytical data on I shows an approximately equimolar ratio of adenine succinate, total P, ribose, sulfate, and *cis*



Ribose-5'-Phosphosulfate (Glutamic, Serine)

glycol (Table II). Acid hydrolysis (1.0 *N* HCl) of I for 10 minutes at 100° released a compound with an R_f identical to ribose-5′-phosphate (R-5′-P) and an ultraviolet absorbing compound (E_4). Substance E_4 showed no diazotizable amine,[7] was free from ribose phosphorus and sulfur and behaved similarly to adenine-succinic acid upon paper electrophoresis at *p*H 3.3 and 6.0.[4] Formic acid hydrolysis of E_4 followed by paper chromatography in several solvent systems yielded adenine, hypoxanthine (minor component), aspartic and fumaric acids, thus completing the identification of E_4 as adeninesuccinic acid.

Since periodate oxidation[8] of I showed a free *cis* glycol, and since R-5′-P was obtained by acid hydrolysis, the phosphate must be attached to the 5 position of ribose. Very mild acid hydrolysis (0.01 *N* HCl for 1 hr. at room temperature) of I produced a peptide and sulfate containing nucleotide which were separable chromatographically. Further treatment of the nucleotide in 0.01 *N* HCl for 10 minutes at 100° liberated inorganic sulfate and adenyl-succinic acid. The sulfate therefore must be attached to the phosphate. Compound I decomposes unless a refrigerated column is used. This suggests the possibility that adenyl succinate isolated from other natural products by ion exchange chromatography is a decomposition product of a larger molecule.

When I was subjected to mild acid hydrolysis (0.01 *N* HCl, 100°, 10 min.) and chromatographed in several systems, a single ninhydrin position spot was obtained which gave glutamic acid and serine in equal concentrations following hydrolysis in 6*N* HCl for 12 hours at 120°. It has not yet been established whether I contains a dipeptide or polypeptide of glutamic acid and serine. Fraction E

(7) J. M. Ravel, R. E. Eakin and W. Shive, *J. Biol. Chem.*, **172**, 67 (1948).

(8) J. S. Dixon and D. Lipkin, *Anal. Chem.*, **26**, 1092, (1954)

TABLE I

PAPER CHROMATOGRAPHY OF FRACTION E

Solvent systems: 1–8, 11 isobutyric/NH_4OH/H_2O 66/1/33; 9, 10 ethanol/NH_4OH/H_2O (8:1:1); 12, 13 ethanol/NH_4OH (95:5); AMP = adenylic acid, ADP = adenosine diphosphate, ATP = adenosine triphosphate, R-P = ribose-phosphate.

		R_f		
		Ultra-violet	Ninhydrin	Phos-phate
1	5′-AMP	0.47		
2	E_1	.05		
	E_2	.15	0.15	
	E_3	.40		
3	5′-ATP	.18		
4	5′-ADP	.23		
5	E_4	.44		0.17
6	5′-RP			.17
7	E_4 (formic hydrolysis)	.84	.23	
		.52		
8	Adenine	.83		
	Hypoxanthine	.51		
	Aspartic		.24	
9	Fumaric	.21	.21	
10	E_4 (formic hydrolysis)	.21	.21	
11	E_2 (10 min., .001 *N* HCl, 100°)	.17	.13	
12	Glutamic		.02	
	Serine		.14	
13	Peptide (hydrolysed)		.02	.14

TABLE II

ANALYSIS OF COMPOUND I

Adenine succinic acid was determined by absorption at 266 mμ using E 16.9×10^3 at *p*H 1.0, ribose by the orcinol method, labile phosphorus by 7 min. hydrolysis in 1 *N* acid, total phosphorus by $HClO_4$ digestion, the color in both cases was developed by the Gomori method. Vicinal glycol was estimated spectrophotometrically.[8] Sulfate was determined colorimetrically after conversion to H_2S,[9] which then reacted with *p*-phenylenediamine to form Lauth's violet.[10]

	Moles
Adeninesuccinic acid	1.00
Ribose	1.12
Labile-P	0.00
Total P	1.05
Sulfate	1.37
cis Glycol	1.27

from another liver preparation contained glycine so this portion of the molecule is probably a variable. The manner of linkage of the peptide to the

(9) C. L. Luke, *Anal. Chem.*, **21**, 1369 (1949).
(10) D. S. C. Pulson and J. D. H. Strickland, *Anal. Chim. Acta*, **6**, 452 (1952).

nucleotide and the sequence of the amino acid residues in the peptide chain are under further investigation.

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Received January 21, 1957

Reprinted from THE JOURNAL OF PARASITOLOGY, June, 1957,
Vol. 43, No. 3, page 290.

RECORDS OF LARVAL *CONTRACAECUM* SP. IN 3 SPECIES OF MYSIDS FROM THE BRAS D'OR LAKES, NOVA SCOTIA, CANADA

Since 1945 the life history of *Porrocaecum decipiens*, the larvae of which infect the flesh of many marine fishes, has been studied by several scientists of the Fisheries Research Board of Canada. Scott (1950, Fish. Res. Bd. Canada, Atl. Prog. Rept. No. **48**: pp. 10–12) suggested that a crustacean might act as a first intermediate host of larval *P. decipiens*. Acting upon this suggestion, Dr. W. F. Black in 1951 and 1952 made extensive collections of invertebrates, principally crustaceans, from the salt water Bras d'Or Lakes, a region with an exceptionally high incidence of *P. decipiens*. In 1955, Black referred to the author for identification nematodes taken from 3 species of mysids. Three nematodes collected in the same area in October 1955 by Mr. D. H. Steele from the crustacean *Mysis mixta* were also sent to the author.

Fourteen nematodes from the mysids, *Erythrops erythrophthalma*, *Mysis mixta* and *Neomysis americana* were examined. All were larvae. Eleven, ranging in length from 2 to 17 mm, showed the characters of the parasitic genus *Contracaecum*. The remaining 3 were too small to permit generic identification.

Tattersall and Tattersall (1951, The British Mysidacea, Ray Society, London) recorded only 1 case of a parasitic worm, that of a cestode, in the Mysidacea. Accordingly, our records are apparently the first of larval *Contracaecum* sp. from the Mysidacea.

In view of the importance of mysids in the diet of many fishes, mysids probably serve as intermediate hosts of some of the species of *Contracaecum* which occur so abundantly in the digestive cavities of marine fishes.—D. M. SCOTT, *Fisheries Research Board of Canada, Biological Station, St. Andrews, N. B. and Department of Zoology, University of Western Ontario, London, Canada.*

"FRB No. 477"

NUTRITION AND METABOLISM OF MARINE BACTERIA

IV. THE PARTICIPATION OF Na^+, K^+, AND Mg^{++} SALTS IN THE OXIDATION OF EXOGENOUS SUBSTRATES BY A MARINE BACTERIUM[1]

N. Tomlinson and Robert A. MacLeod

Abstract

The inorganic ion requirements for the preparation, storage, and oxidative activity toward exogenous substrates of washed cell suspensions of a marine bacterium have been investigated.

Washing with distilled water greatly reduced the activity of cells toward exogenous substrates. There was found to be a relatively non-specific requirement for the presence of inorganic ions in the wash solution for the preparation of cell suspensions that are metabolically active when fresh.

To maintain metabolic activity of the cells on storage, a specific requirement for Na^+, K^+, and Mg^{++} was demonstrated. In addition, Mg^{++} was active in preventing cytolysis. Mn^{++} could replace Mg^{++} in the latter capacity but not in some function of Mg^{++} connected with oxidative processes.

For oxidation of exogenous substrates, a requirement for Na^+ and K^+ but not Mg^{++} was demonstrated. The optimum Na^+ concentration lay between 0.1 and 0.3 *M* and K^+ between 0.01 and 0.1 *M*.

Introduction

Marine bacteria differ from all land forms investigated in requiring a relatively high concentration of Na^+ in the medium for growth (11, 12). In view of this requirement, an investigation of the effects of sodium chloride and certain other inorganic salts on the oxidation of exogenous substrates by a marine bacterium was undertaken with the object of attempting to learn something of the role of these salts in the metabolism of the organism.

The present paper describes results indicating that Na^+ and K^+ together are essential for the oxidation of exogenous substrates by washed cells of a marine bacterium, and in addition that these two ions, together with Mg^{++}, function in preventing the loss of oxidative ability during aging.

Materials and Methods

The organism studied in this investigation was isolated from clams and has been designated B16 in this and previous communications. A marine form according to the definition of Zobell and Upham (18), it has now been tentatively identified as a species of either *Pseudomonas* or *Spirillum*.[2] The method used to carry cultures of the organism and some of its requirements for growth have been described (13).

[1]Manuscript received January 21, 1957.
Contribution from the Fisheries Research Board of Canada, Technological Station, Vancouver, B.C.
[2]We are indebted to Dr. Einar Leifson, Loyola University, Chicago, Ill., for investigating the classification of this organism.

A non-synthetic medium was used. It consisted of artificial sea water[3] supplemented with 0.021% K_2HPO_4-KH_2PO_4 (pH 6.7), 0.1% $(NH_4)_2SO_4$, 0.8% nutrient broth, and 0.5% yeast extract. The medium was sterilized by autoclaving at 15 lb. pressure for 15 minutes.

For the preparation of washed cell suspensions, cultures were grown in 250 ml. portions of medium dispensed in 2-liter Erlenmeyer flasks. Inoculated flasks were incubated at 25° C. on a rotary shaker for 18 hours. Cells were harvested by centrifuging and were washed by decanting the supernatant liquid, resuspending the cells in a volume of washing liquid (*vide infra*) equivalent to one-half the volume of culture from which the cells had been separated, centrifuging the suspension, and again decanting the supernatant liquid. This procedure was repeated twice. The cells were then suspended in a suitable solution and the volume was adjusted to contain a known dry weight of cells. The dry weight was measured by determining the optical density of suspensions with an Evelyn colorimeter (660 mμ filter) then converting the optical density to dry weight by means of a previously calibrated curve.

Conventional techniques (16) were used in Warburg respirometer experiments. The experimental conditions are described in the tables and figures.

Results

Preliminary Investigation of the Influence of Various Washing Solutions and Suspending Media on the Oxidative Activity of Washed Cells

The effects of several washing and suspending media on the oxidative activity of whole cells of strain B16 were determined. The media used were distilled water, 0.0475 *M* sodium phosphate buffer (pH 7.1), 0.4 *M* NaCl (the concentration of this salt in artificial sea water), and artificial sea water (footnote 3). L-Alanine and sodium succinate were selected as substrates because they had been found to be good sources of carbon for growth of the organism, and therefore might be actively oxidized by the cells.

Cells were examined for ability to oxidize the two substrates immediately after the suspensions were prepared, and again after they had been stored for 7, 14, and 22 days at 1° C.

Freshly prepared cells, with the exception of those washed in distilled water, were all most active toward the substrates when the suspending medium contained the salts of artificial sea water (Table I). With cells washed in distilled water, sodium phosphate buffer was the best suspending medium. At no time did water washed cells exhibit oxidative activity with the substrates comparable to the best shown by cells washed in any one of the three solutions. The relatively low activity of these water washed cells toward substrates decreased very rapidly with time at 25° C. It should be noted that large losses of cells occurred during washing with distilled water, apparently due to cytolysis, but the cells remaining at the end of the procedure

[3]Composition of artificial sea water from Lyman and Fleming (9) with slight modifications: NaCl, 0.4 *M*; Na_2SO_4, 0.0275 *M*; $NaHCO_3$, 0.0023 *M*; KCl, 0.0089 *M*; KBr, 0.00081 *M*; $MgCl_2$, 0.052 *M*; $SrCl_2$, 0.00015 *M*; H_3BO_3, 0.00042 *M*.

TABLE I

THE INFLUENCE OF THE COMPOSITION OF THE WASHING SOLUTION AND SUSPENDING MEDIUM ON OXYGEN UPTAKE BY WHOLE CELLS OF B16

Wash solution*	Suspending medium*	Substrate		
		None	Na succinate	L-Alanine
		O_2 uptake in 30 min. (μl.)		
Distilled water	Distilled water	0	32	0
	Buffer	95	142	151
	NaCl	2	19	10
	Sea water	22	36	30
Buffer	Buffer	74	123	146
	NaCl	64	84	68
	Sea Water	92	211	223
NaCl	NaCl	75	68	151
	Sea water	83	264	223
Sea water	Sea water	91	261	228

*Composition of wash solutions and suspending media:
buffer, Na_2HPO_4–NaH_2PO_4, 0.0475 *M*, pH 7.1;
NaCl, 0.4 *M*;
sea water (artificial), see Footnote 3.

Each Warburg vessel contained 7 mg. dry weight of cells in a final volume of 2.8 ml. of suspending medium; 5 μM. of substrate added from sidearm after 15 min. equilibration in water bath; temp. 25° C.; gas phase air; 0.2 ml. 20% KOH in center well.

appeared whole on microscopic examination. However, the effect of sea water on oxygen uptake by these cells, when compared with that of sea water on cells washed in any of the three solutions, strongly suggests that they have suffered some damage during washing in water.

The behavior of the different cell preparations toward the two substrates was very much the same in all cases except that some impairment of the oxidation system for succinate occurred during washing of the cells in dilute buffer.

Very marked differences in activity were found between suspensions in the different media following storage at 1° C. for varying periods of time. Those stored in distilled water lost nearly all their activity toward the two substrates in 7 days. The cells in sodium phosphate buffer lost activity less rapidly, but were nearly inactive at the end of 22 days. Stored in 0.4 *M* NaCl, cells began to show a decrease in activity at 7 days and had lost about 75% of their activity at the 22nd day. In artificial sea water, cells maintained full activity toward L-alanine for 22 days, but lost about 60% of their activity with sodium succinate between 14 and 22 days. Subsequently it was found that the stability of different suspensions in sea water varied, but was always greater than that of suspensions in other solutions.

The Components of Artificial Sea Water Responsible for Its Influence on the Oxidative Activity of Freshly Washed Whole Cells

Since Na^+, K^+, and Mg^{++} are the only cations in artificial sea water known to be required for growth of B16 (11), the effect of their chloride salts, singly

TABLE II

THE ABILITY OF CERTAIN SALT SOLUTIONS TO REPLACE SEA WATER IN INCREASING OXYGEN UPTAKE BY WHOLE CELLS OF B16*

	Substrate		
	None	Na succinate	L-Alanine
Suspending medium†	O_2 uptake in 30 min (μl.)		
Buffer	51	65	118
Buffer, NaCl, KCl	72	131	239
Buffer, NaCl, KCl, $MgCl_2$	62	122	223
Buffer, sea water	62	114	220

*Cells washed in Na_2HPO_4–NaH_2PO_4, 0.0475 *M*, pH 7.1.
†Concentrations in Warburg vessels:
buffer, Na_2HPO_4–NaH_2PO_4, 0.0475 *M*, pH 7.1;
NaCl, 0.46 *M*; KCl, 0.01 *M*; $MgCl_2$; 0.05 *M*.
Other experimental conditions described in Table I.

and in combinations in the suspending medium, on the oxygen uptake of sodium phosphate buffer washed cells was investigated.

Freshly washed cells oxidized both substrates as rapidly when suspended in a solution of NaCl and KCl (at the concentration of their cations present in artificial sea water) as when suspended in artificial sea water (Table II). The addition of $MgCl_2$ to the NaCl–KCl solution reduced the endogenous oxygen uptake to the level observed in sea water, without having any detectable effect on oxidation of the exogenous substrates. The three salts in other combinations, or singly, were not effective in increasing oxygen uptake with exogenous substrates.

The Components of Artificial Sea Water Responsible for Its Influence on the Changes in Oxidative Activity of Whole Cells During Aging

From the above results, it was thought that the NaCl–KCl solution might be a suitable substitute for sea water as a washing and storing medium. However, when cells were stored in NaCl–KCl solution, NaCl–KCl–$MgCl_2$ solution, or in sea water at 1° C., it was found that the cells in NaCl–KCl solution lost activity more rapidly than did those in the other two solutions. Thus it appeared that Mg^{++} was concerned in maintaining the oxidative ability of washed cells.

This effect of Mg^{++} was investigated by preparing cells in several different solutions, then observing the effect of holding them at 25° C. The results are presented in Table III. Cells washed and suspended in NaCl–KCl solution lost their ability to oxidize the two substrates in 20 hours, but showed an increase in endogenous oxygen uptake. Cells suspended in sea water showed much smaller losses in activity toward both substrates in the same period of time. It can be seen that the protective action of sea water on storage could be almost duplicated by adding $MgCl_2$ to the mixture of NaCl

TABLE III

THE INFLUENCE OF Mg^{++} ON THE LOSS OF OXIDATIVE ABILITY BY WASHED CELLS OF B16 DURING STORAGE AT 25° C.

Wash solution*	Substrate	Storage time (hr.) 0	20	44	146
		O_2 uptake in 30 min. (μl.)			
NaCl, KCl	None	52	95	64	19
	Na succinate	204	116	68	40
	L-Alanine	220	94	58	24
NaCl, KCl, $MgCl_2$	None	36	71	86	29
	Na succinate	212	193	156	37
	L-Alanine	218	256	200	29
NaCl, KCl, $MgCl_2$, $MgSO_4$	None	36	60	95	25
	Na succinate	237	226	193	44
	L-Alanine	200	253	227	28
Sea water	None	48	92	116	23
	Na succinate	208	242	196	40
	L-Alanine	221	279	249	28

*The solution is that in which the cells were washed and stored. Salt concentrations: NaCl, 0.46 *M*; KCl, 0.01 *M*; $MgCl_2$, 0.052 *M* (0.0245 *M* when $MgSO_4$ present); $MgSO_4$, 0.0275 *M*.

The suspending medium in the Warburg cups contained the same salts at the same concentrations as were present in the cell suspension being examined, plus Na_2HPO_4-NaH_2PO_4 buffer, 0.0475 *M*, pH 7.1.

Other experimental conditions described in Table I.

and KCl. The further addition of $SO_4^=$ (as $MgSO_4$) helped retain the capacity of the cells to attack succinate. During the experiment outlined in Table III, changes in the optical density of the cell suspensions were measured. That of the cells in NaCl-KCl solution decreased from 0.58 to 0.129 (at 660 mμ) during the first 20 hours of storage, while the optical density of the other suspensions decreased to only 0.47 in 6 days. Microscopic examination showed that the suspension in the NaCl–KCl solution after 20 hours was a mixture of cell debris and apparently whole cells, whereas cells in the other solutions remained whole during the 6 day period.

It was found that the increase in endogenous activity observed in aged cell suspensions (Table III) could be accounted for by the presence in the suspending medium of soluble products arising from the lysed cells. The supernatant solution obtained when an aged cell suspension was centrifuged contained material capable of being very rapidly oxidized by the remaining aged cells. Further study revealed that the presence of Na^+ and K^+ as well as Mg^{++} was required to maintain the oxidative activity of the whole cells on aging (Table IV). Since the NaCl concentration was much higher than that of the other two salts in the suspending solution, the ability of sucrose to replace it in the solution was tested. Sucrose showed no capacity to replace NaCl in retaining the oxidative activity of the resting cells with age.

TABLE IV

THE INFLUENCE OF NaCl, KCl AND SUCROSE ON THE LOSS OF OXIDATIVE ACTIVITY OF WHOLE WASHED CELLS DURING AGING

	Fresh suspension			Aged suspension†		
	Substrate		Δ	Substrate		Δ
	None	L-Alanine		None	L-Alanine	
Storage solution*	O_2 uptake in 60 min. (μl.)					
$MgCl_2$	78	269	191	18	21	3
$MgCl_2$, NaCl	76	256	180	37	73	36
$MgCl_2$, KCl	86	289	203	26	28	2
$MgCl_2$, KCl, sucrose	70	257	187	15	8	−7
$MgCl_2$, KCl, NaCl	81	283	202	50	148	98

*Concentrations in storage solutions: $MgCl_2$, 0.052 *M*; NaCl, 0.1 *M*; KCl, 0.01 *M*; sucrose, 0.2 *M*.

†Cell suspensions stored 20 hr. at 25° C.

Cells were washed three times in 0.052 *M* $MgCl_2$, then suspended in storage solution indicated. The Warburg vessels received 1 ml. of the suspension being examined (7 mg. dry weight of cells), and additions such that each vessel contained $MgCl_2$, NaCl, and KCl in final concentrations of 0.052 *M*, 0.1 *M*, and 0.01 *M*, respectively. With the suspension stored in the sucrose containing solution, sucrose was present in the flasks in addition at a concentration of 0.2 *M*. Other experimental conditions as in Table I.

Detailed Examination of the Influence of NaCl and KCl on Oxygen Uptake by Whole Cells

To examine in detail the influence of NaCl and KCl on the respiratory activities of B16, advantage was taken of the fact that whole cells capable of excellent oxidative activity when fresh could be obtained by washing the cells in 0.052 *M* $MgCl_2$. These washed suspensions contained 13 to 15 μg. K^+ and less than 2 μg. Na^+, determined by flame spectrophotometry, per ml. of suspension containing 7 mg. dry weight of cells (cf. 2).

The effect of various concentrations of NaCl and KCl, separately and in different combinations, on the oxidation of L-alanine, sodium succinate, and D-glucose was examined. Some of the results obtained with L-alanine as substrate are presented in Figs. 1–3. The data of Fig. 1 demonstrate that with a constant KCl concentration the rate of oxidation of the substrate is controlled by the concentration of NaCl in the medium, and that the rate remains essentially constant for at least 1 hour after the substrate is tipped from the sidearm, unless the substrate is exhausted earlier. The same has been found to be true for variations in the concentration of KCl in the medium when the NaCl concentration is held constant. Thus the data of Figs. 2 and 3 present changes in rate of oxygen uptake occurring in response to different NaCl or KCl concentrations, and not the effect of losses in enzyme resulting from denaturation under adverse conditions.

The response of cells to Na^+ in the presence of varying levels of K^+, using L-alanine as substrate, is shown in Fig. 2. In the presence or absence of added K^+ the rate of oxidation increased to a maximum and then decreased as

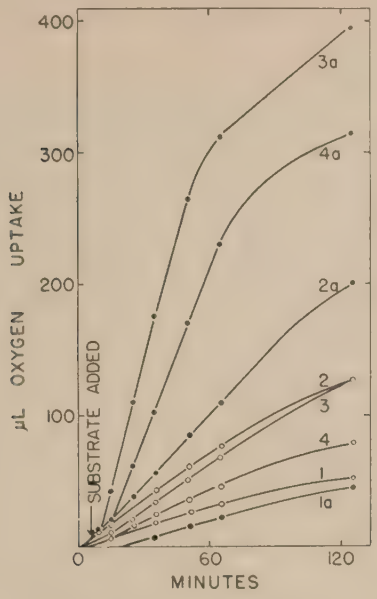

FIG. 1. The influence of NaCl concentration on the endogenous respiration of, and L-alanine oxidation by, marine bacterium B16. O_2 uptake: ○———○, endogenous; ●———●, with L-alanine as substrate.

NaCl concentrations: Curves 1 and 1*a*, 0.0;
Curves 2 and 2*a*, 0.03 *M*;
Curves 3 and 3*a*, 0.2 *M*;
Curves 4 and 4*a*, 0.6 *M*.

Each Warburg vessel contained 7 mg. dry weight of cells washed in 0.052 *M* $MgCl_2$, and suspended in a solution containing $MgCl_2$, 0 052 *M*; KCl, 0.01 *M*; and NaCl as indicated above. Other conditions described in Table I.

the Na^+ level was increased. A higher level of Na^+ was required for maximum rate of oxygen uptake in the presence of the substrate than in its absence. As the K^+ level was increased progressively from a suboptimal level (Fig. 2, A to E) the amount of Na^+ required for maximum rate of oxygen uptake in the presence of the substrate was increased slightly (from 0.2 to 0.25 *M*) and the amount of Na^+ required to produce inhibition also increased, indicating some antagonism between Na^+ and K^+. That K^+ may also have capacity to carry out some of the functions of Na^+ is evident from the fact that there was a considerably greater rate of oxygen uptake by cells at suboptimal concentrations of Na^+ (0.03 to 0.1 *M*) with K^+ added at the 0.4 *M* level as compared with that by cells in the same Na^+ concentrations but with levels of K^+ of 0.01 *M* and lower.

The response of the resting cells to K^+ at a constant level of Na^+ in the suspending medium is shown in Fig. 3. In the absence of added K^+ a slow oxidation of substrate was observed which could be accounted for by the small amount of K^+ known to be retained by the cell suspension after washing. The addition of even small amounts of K^+ produced a marked increase in the rate of oxidation of the substrate.

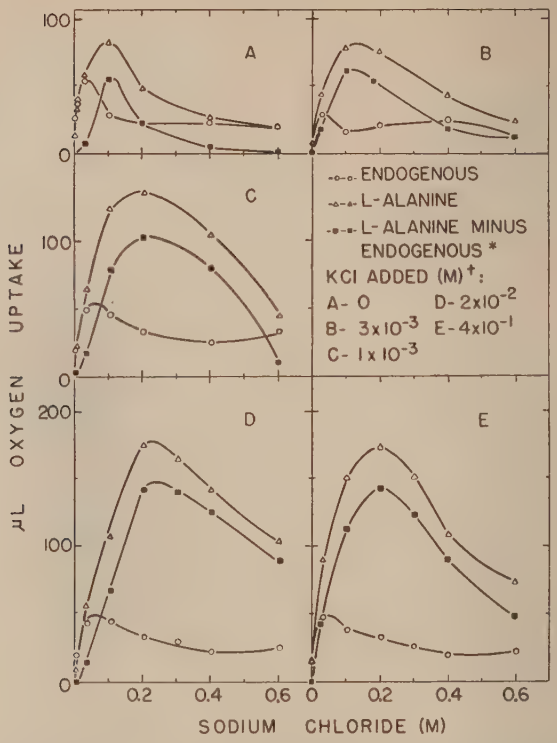

FIG. 2. The influence of various concentrations of NaCl and KCl on the endogenous respiration of, and L-alanine oxidation by, marine bacterium B16. Each Warburg vessel contained 7 mg. dry weight of cells washed and suspended in 0.052 *M* $MgCl_2$ solution, to which was added NaCl and KCl as indicated. Other conditions described in Table I.

*Tomlinson and MacLeod (14).

†The washed cell suspensions used contained sufficient K^+ to bring the concentration of this ion to 1.3×10^{-4} *M* in each vessel before the addition of KCl.

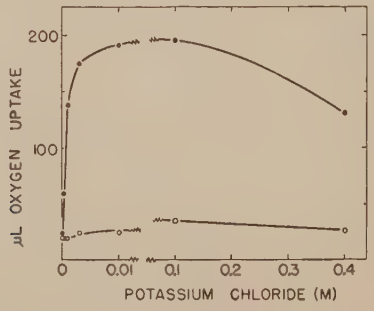

FIG. 3. The influence of various concentrations of KCl on the endogenous respiration of, and L-alanine oxidation by, marine bacterium B16. O_2 uptake: ○———○, endogenous; ●———●, with L-alanine as substrate. Concentrations in Warburg vessels: NaCl, 0.02 *M*; $MgCl_2$, 0.052 *M*; KCl added as indicated. Other conditions described in Fig. 2.

Sucrose as a Substitute for NaCl in the Oxidation of Exogenous Substrates by Whole Cells of B16

In view of the report that " . . . moderate dilutions of isotonic sucrose give the same per cent reduction of luminescence and respiration (of a marine bacterium) as moderate dilutions of sea water . . . " (7) and of the recent finding by MacLeod and Onofrey (11) that sucrose exhibits a limited sparing effect on the requirement for Na^+ by B16 for growth, it was decided to investigate the possibility that sucrose might be capable of replacing NaCl, at least partially, in its effect on the oxidation of exogenous substrates by whole cells. B16 grown in the complex medium used in this work does not oxidize sucrose.

TABLE V

SUCROSE AS A SUBSTITUTE FOR NaCl IN THE OXIDATION OF L-ALANINE BY WHOLE CELLS OF B16

Addition to suspending medium*	Substrate		Δ
	None	L-Alanine	
	O_2 uptake in 30 min. (μl.)		
None	56	145	89
NaCl to 0.2 *M*	42	222	180
KCl to 0.11 *M*	43	171	128
Sucrose to 0.1 *M*	45	150	105
" to 0.2 *M*	33	136	103
" to 0.4 *M*	18	41	23

*Each Warburg vessel contained 7 mg. dry weight of cells (washed in $MgCl_2$, 0.052 *M*); $MgCl_2$, 0.052 *M*; NaCl, 0.1 *M*; KCl, 0.01 *M*, together with the additions indicated above. Experimental conditions as described in Table I.

The data of Table V show that under conditions where increasing the concentration of NaCl from 0.1 to 0.2 *M* doubled the rate of oxidation of L-alanine, and where 0.1 *M* KCl had a marked ability to perform the same function, the substitution of 0.1 or 0.2 *M* sucrose for the additional 0.1 *M* NaCl produced only a very small increase in the rate of oxidation of L-alanine. The substitution of 0.4 *M* sucrose was distinctly inhibitory. As 0.2 and 0.4 *M* sucrose are concentrations that exhibited a sparing effect for NaCl in the growth of B16 (11) it appears that this effect cannot be attributed to a favorable influence on the rate of oxidation of exogenous substrates by the cells.

Mn^{++} as a Substitute for Mg^{++} in Preventing Lysis and Loss of Oxidative Activity by Whole Cells of B16

In view of the known ability of Mn^{++} to substitute for Mg^{++} in preventing the autolysis of a terrestrial bacterium (10), it was of interest to see if a similar effect might be observed with a marine form. Cells were washed and suspended as usual in NaCl-KCl, NaCl-KCl-$MgSO_4$, and in NaCl-KCl-$MnSO_4$ solutions. The suspensions were incubated at 25° C. for 20 hours

then examined for changes in optical density and in oxidative ability. After 20 hours' storage the suspension in NaCl–KCl solution was apparently inactive toward the substrates, as usual, and the activity toward the substrates was not increased by the addition of Mg^{++}. The suspension of NaCl–KCl plus $MnSO_4$ took up no oxygen, but when Mg^{++} was added some oxygen uptake occurred and it was evident that the suspension had retained more oxidative activity towards the substrates than had the suspension in NaCl–KCl solution. This activity, however, was much lower than that of cells stored in the solution containing Mg^{++}. Examination of the suspensions showed that Mn^{++} was at least as effective in preventing the lysis of cells as was Mg^{++}. It thus appeared that Mn^{++} could replace Mg^{++} in preventing cell lysis, but could not replace it in some function related to the oxidative activity of the cells.

Discussion

MacLeod and Onofrey (11) have shown that bacteria from marine sources have salt requirements for growth different from those of terrestrial forms. The present findings indicate that other differences also exist between whole cells of bacteria from these sources. These differences are apparent in the inorganic ion composition of the washing solutions necessary for use in the preparation of metabolically active whole cell suspensions, in the composition of the solutions capable of maintaining oxidative activity of the cells on storage, and in the inorganic ion requirements of the cells for the oxidation of exogenous substrates.

With many bacteria from terrestrial sources, e.g. *Micrococcus* (8), *Lactobacillus* (15), distilled water has been used as the washing solution to prepare suspensions that in dilute phosphate buffers exhibited satisfactory metabolic activity with exogenous substrates. The cells of the marine bacterium studied in the present work, however, were found to possess negligible oxidative activity toward exogenous substrates after washing with distilled water, and the activity was not improved by the addition of artificial sea water to the suspending medium. The results indicate also that any of the salt solutions tested, NaCl, $MgCl_2$, or phosphate buffers, could be used to prepare cell suspensions of B16 metabolically active when fresh. There was thus a definite though apparently non-specific requirement for the presence of ions in the wash solution. Johnson (5) has previously reported that distilled water was unsatisfactory for use in washing marine bacteria.

The ion requirements were highly specific, however, for the maintenance of oxidative activity of washed cells on storage. Na^+, K^+, and Mg^{++} have all been shown to be required by organism B16. Mg^{++}, in addition, played a part in preventing lysis of the cells on storage. The relation, if any, between these two roles of Mg^{++}, however, cannot be established by the results presented here. Goucher *et al.* (3, 4) have shown that the maintenance of the integrity of the respiratory system of *Azotobacter agile* is dependent on the Mg^{++} content of the suspending medium, though no reference was made to the effect of the ion on cellular structure. In any event, although Mg^{++}

loes have a similar function in both land and marine forms in maintaining espiratory activity on aging, no evidence of a requirement for Na^+ and K^+ n this capacity in land forms has been reported. Johnson and Harvey (6) iave reported that Mg^{++} affected the volume, rate of sedimentation, and ptical appearance of cells of *Achromobacter fischeri* in dilute solution.

For the oxidation of exogenous substrates, a requirement for the addition of Na^+ and K^+ but not Mg^{++} to the suspending medium has been demonstrated for the marine bacterium B16. This requirement for Na^+ and K^+ together for the rapid oxidation of exogenous substrates has, to our knowledge, not been observed with a terrestrial bacterium and does not appear to have been recognized in the past with marine bacteria (1, 5) or halotolerant forms (17).

Johnson and Harvey (7), working with a marine bacterium, *A. fischeri*, and Yamada and Shiio (17) with a halotolerant bacterium, *Bacillus pumilus*, concluded that the function of NaCl and KCl in the respiration of these organisms was related to osmotic pressure. In the first instance, the conclusion was based chiefly on the fact that sucrose could largely replace NaCl, KCl, or sea water in their effects on the respiration of the cells. However, in the present work with marine bacterium B16, sucrose failed to substitute for NaCl in the oxidation of exogenous substrates by whole cells and in the preservation of their oxidative activity on aging.

The role of NaCl and KCl in the metabolism of B16 is more complex than that contemplated for these salts in *A. fischeri* and *B. pumilus*. In B16 there is a function specific for K^+ that appears to be inhibited by Na^+, a second function that either ion can perform, and a third function specific for Na^+ for which the apparent optimum concentration of this ion is nearly independent of KCl concentrations between 0.001 and 0.4 *M*. This may, of course, be an oversimplification, as these functions are only the minimum number that can be distinguished in B16 from the results recorded in Fig. 2.

Claren (1) reported a stimulation of the oxidation of glucose and fumarate by a marine bacterium suspended in NaCl solution on the addition of a mixed Na-K phosphate buffer, but attributed the effect to phosphate. Johnson (5) reported a phosphate buffer to be stimulatory to the respiration of marine bacteria suspended in NaCl solution, but the cations of the buffer were not mentioned. Similarly, Yamada and Shiio (17) reported stimulation of respiration of a halotolerant bacterium by either NaCl or KCl in a phosphate buffer of unspecified cation content. Investigation of the effect of phosphate buffers with B16 has shown that for freshly washed cells it is the cations of the buffer that are responsible for its effects and not the phosphate ion. Thus, NaCl stimulated substrate oxidation by cells in potassium phosphate buffer, but not by those in sodium phosphate, while for KCl the reverse was true. In addition, it has been found that for cells freshly washed in NaCl-KCl solution, phosphate buffer can be omitted from the Warburg flask without significant effect on oxidation of L-alanine, sodium succinate, or D-glucose.

These results suggest that the results of Claren (1) were probably due to the K^+ of the buffer, and indicate that a similar explanation may apply to the results of Johnson (5) and Yamada and Shiio (17).

At least two explanations are possible for the fact that the NaCl concentrations necessary for optimum endogenous respiration and for oxidation of exogenous substrates are different (Fig. 2). At first this implies a different optimum NaCl concentration for activity of some enzyme(s) concerned with oxidation as opposed to others concerned, for instance, with activation of exogenous substrates. Alternatively, however, it may be that at low concentrations of NaCl some mechanism associated with the destruction of cellular components may be favored and this could possibly free materials within the cells oxidizable by them, thus bringing about the apparent increase in endogenous respiration.

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Methyl Esters from Marine Oils

BY DR. F. A. VANDENHEUVEL and P. M. JANGAARD,
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Polyesters, with various industrial applications, can be produced cheaply from marine oils, according to a Fisheries Board research team in the Maritimes. The chemistry and plant economics of the process are discussed in this article.

AS potential raw materials for the manufacture of fatty compounds of widely different characteristics, marine oils are unique among fats of natural origin. Their complexity is exemplified in Figure 1 which shows the fatty acid composition of a typical sample of herring oil. The relative amount of each acid is indicated by the extent of a black rectangular area, the sum of all areas being 100%. It is seen that the even carbon series from C_{10} to C_{24} are present, with unsaturation ranging from 0 to 6 double bonds. These acids are distributed among the glycerides in a near-random fashion.

Consequently the direct application of physical means of separation (solvent segregation, fractional crystallization) to this oil, leads to glyceride fractions which are far from reflecting the considerable differences in properties displayed by the component acids. Accordingly, preliminary breakdown of the glycerides is a necessary step toward an efficient fractionation.

This may be done by two methods as follows;

(a) Fat hydrolysis — giving acids as products,

(a) Alcoholysis — giving alkyl esters as products.

The first is the classical method, while the second has not yet gained wide commercial acceptance. This paper attempts to show that the latter process (using methyl alcohol) is superior in economics and also in that esters are better reagents for further processing than acids.

Earlier Research

As early as 1944, Wright *et al.* (1) had shown that alkyl ester production from low molecular weight alcohols offers advantages over fat splitting by conventional hydrolytic processes. They mentioned the ease of recovery of glycerol in good yield and the reduction of plant size and labour for equivalent production. Our own experiments and study confirmed this and showed that the yield of U.S.P. glycerol could be even higher than these authors had indicated. On the basis of continuous operation, splitting fats through methanolysis is at least as economical as hydrolysis.

Reproduced by permission from Canadian Chemical Processing March, 1957, pages 40-42, 44, 46.

Again Wright *et al.* had shown the possibility of replacing acids by esters in all reactions involving polyols. With the catalyst of their choice the esterification of these hydroxyl functions proceeded at least as easily with esters as with acids. Our own work indicated

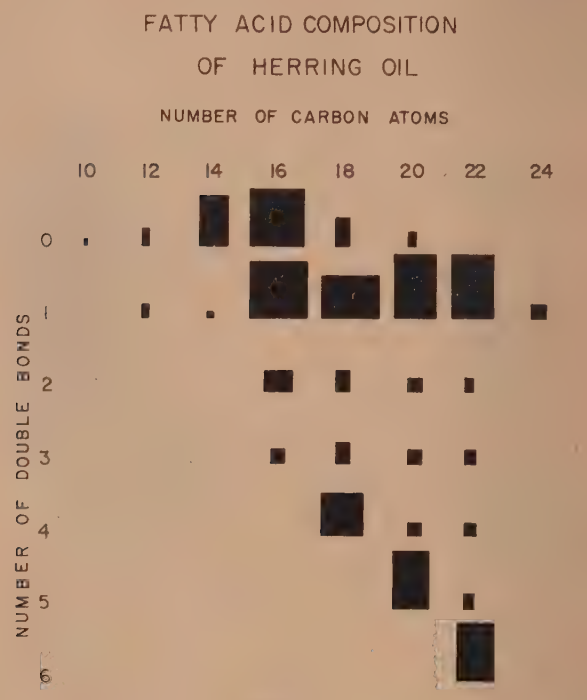


Figure 1

that methyl esters, under proper conditions, were much more reactive than the corresponding acids in such reactions. Furthermore, the products were lighter in colour and in general of higher quality than those obtained from acids. It was thus established that methyl esters constitute a superior raw material for the production of mono-glycerides, alkyds, drying or non-drying polyesters and varnishes. To this must be added the possibility of direct reduction to alcohols by the well established sodium process. Our efforts were then directed towards finding an efficient and economical method for ester fractionation.

The potential advantages of alkyl ester production and use are only beginning to be generally appreciated today, more than a decade after Wright *et al.* predicted a bright commercial future for these materials. Just recently a firm has offered various grades of methyl

linoleate obtained from safflower oil. Among other points of interest in this announcement, the price of these high quality esters is in the same range as that of the original oil. This may be taken as evidence that the production and fractionation of methyl esters from glyceride oils is a sound commercial venture.

At the same time, a series of new products obtained from methyl esters has been announced elsewhere. Some of these, such as the sucrose esters, will be manufactured on a very large scale and it would seem evident that the commercial importance of methyl esters is going to be considerable in the near future.

Under these circumstances, the method described below may be of some interest. Designed to produce cheap methyl ester fractions of high quality from any oil, it is particularly attractive when applied to marine oils as the fractions thus obtained cover a wide range of specific properties.

The method finally selected for the separation of the products formed from methanolysis was counter current solvent segregation followed by fractional distillation. Nitromethane was chosen as the solvent in the former process because of its efficiency at room temperature and at low solvent to ester ratio.

Experimental Method

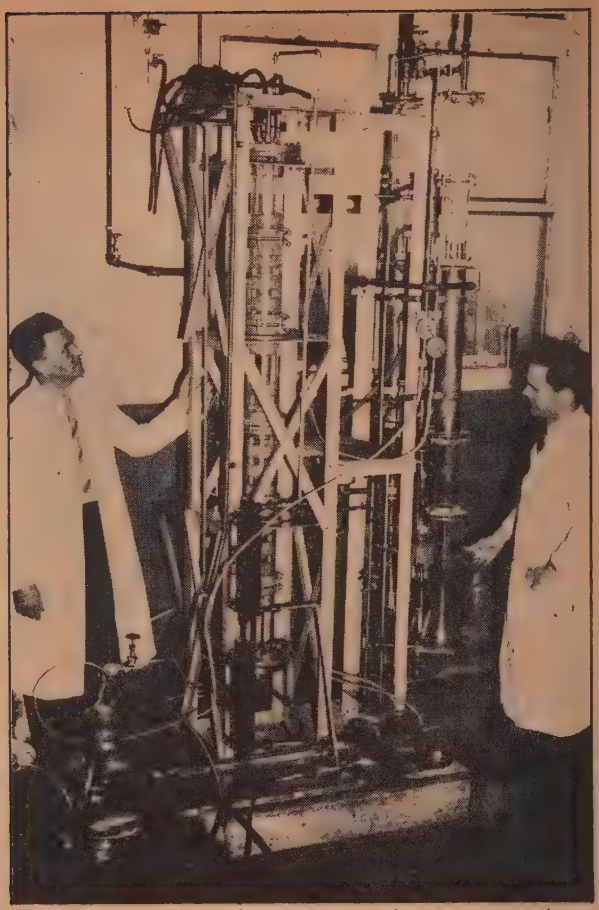
The extraction column used in our pilot plant experiments is made of 4-inch diameter industrial glass pipe. It is 6 feet high and contains 15 stages made of Raschig rings, packed 2 inches thick between perforated metal plates. These "resting" stages alternate with zones of mild agitation. Stirring in these zones is created by the slow rotation of two short arms made of small sections of steel rod. These are slipped in holes bored in the common stirrer shaft which runs through the whole length in the centre of the column.

The solvent entering at the top, and the methyl esters entering at the bottom of the column, are each injected by adjustable metering pumps. A rotameter type gauge on each circuit is used in adjusting the rate flow and for occasional checks.

An even gradient of temperature is established from top to bottom of the column by circulating coolant through four metal tubes running through the whole length of the column. These pipes also function as supports for the packed stages.

Results

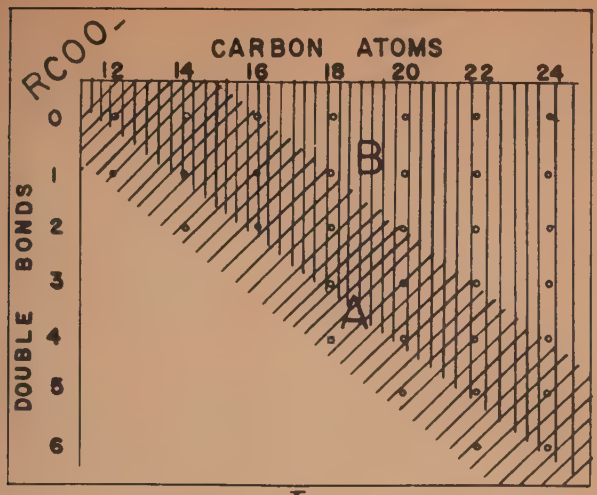
In the run described below, the temperature was 5 degrees C. at the bottom and 15 degrees C. at the top of the column.



The authors are shown here operating the extraction column used for separating methyl esters obtained from herring oil.

With a solvent-ester ratio of 2 to 1, the column could process 30 lb. of methyl esters per hour. Continuous treatment at the rate of 10,000 lb. in 24 hours would require a column only 15 inches in diameter and 10 feet high.

With herring oil methyl esters of I.V. 126, the extract phase running from the bottom of the column contained one-third of the esters (Fraction A). The solvent was stripped from these by flash distillation. Their iodine value was 220. The raffinate phase running from the top of the column was stripped of the 27% nitromethane it contained. The iodine value was 80 (Fraction B). An approximate description of the distribution of methyl esters between the two fractions is given in diagram I, Figure 2, where the wide diagonal band indicates the extent to which compositions overlap. It is seen that Fraction A contains most of the mono-olefinic esters and Fraction B con-



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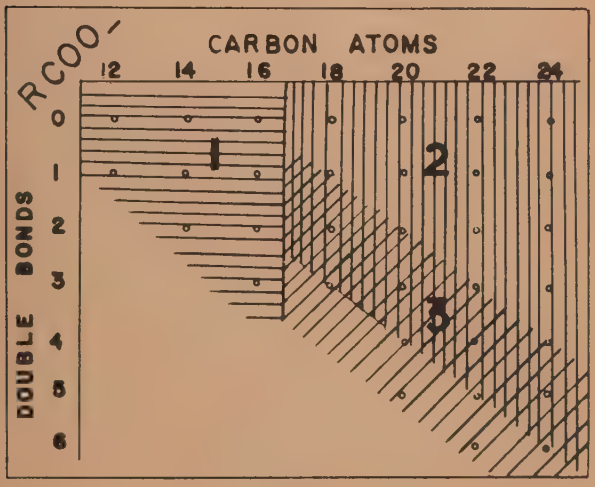

II

Figure 2

tains most of the highly unsaturated ones. Both fractions share the saturated esters. By fractionally distilling both fractions until all the C16 series of esters had distilled off, and uniting the distillation heads thus obtained, a fraction of iodine value 35, containing most of the saturated esters initially present, was obtained (Fraction I). Distillation was then continued without fractionation for both fractions A and B. Fraction II, iodine value 130, was obtained from Fraction AB. The residue of this distillation amounted to about 3% of the total Fraction AB. It contained 50% cholesterol,

the rest being made up partly of glycerides which escaped methanolysis and partly of polymerized material. Extracting this material with hot methanol, gave almost pure cholesterol. The cholesterol in this distillation residue represented practically all the cholesterol initially contained in the herring oil.

Continued distillation of Fraction B4 gave Fraction III, iodine value 250. The residue amounted to 4% of the original Fraction B4

Diagram II, Figure 2, shows the approximate distribution of methyl esters among Fractions I, II, and III; most of the saturated esters are found in Fraction I, most of the mono-olefinic in Fraction II, and most of the highly unsaturated esters in Fraction III. Hence the specific character of these products. Fraction I is a colourless, almost odourless liquid; Fraction II is a very pale yellow liquid with a faint paint odour. Fraction III is a pale yellow liquid having a pronounced paint odour.

Figure 3 is a chart describing the products and by-products obtained from five tons of herring oil when methanolysis is followed by the application of the simple procedure described above.

Production Costs

The following is an approximate estimation, based on data from both laboratory and pilot plant operation, of the production costs of methyl ester fractions from herring oil produced according to the scheme just described. In this estimation, the byproduct sales returns are subtracted from the total operational costs and the resulting difference is divided by the total methyl ester output. Thus the cost per pound of methyl esters is obtained with no distinction as to the type. It must be understood that this is not a normal accounting procedure; it is merely intended to give some idea of the overall economics of the process.

It was assumed that the three-step process (methanolysis, segregation, distillation) is a continuous one, being carried out three hundred 24-hour days per year at the rate of 5 tons of oil per day. It is moreover assumed that the oil costs 8 cents per pound, and the recovered cholesterol is worth $7.00 per pound. It is also assumed that the recovery of glycerol, which is obtained through a simple distillation process, is continuous while that of cholesterol is semicontinuous.

Some guesses had to be made, for example regarding the staff and salaries; in such cases general data derived from similar processing steps in established industries were used.

Total capital outlay (Site — $20,000; building, 100,000 cu. ft. — $80,000; Equipment installed — $330,000; First investment in raw materials — $30,000)	$460,000

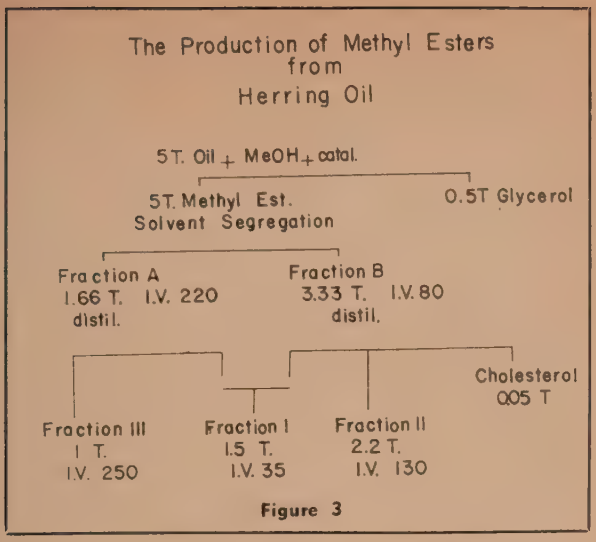

Figure 3

Interest at 7%	$ 32,200	per	annum
Depreciation (5% on building, 14% on equipment)	50,200	"	"
Wages and salaries, for 18 persons . .	78,000	"	"
Operating costs, reagents, chemicals, solvent losses, water, power, steam packaging, maintenance, operation of motor vehicles)	80,000	"	"
Oil (3,000,000 lb. at 8 cents per lb.)	240,000	"	"
Total debenuture (oil, operating costs, wages and salaries, interest and depreciation)	480,400	"	"
Byproduct sales (glycerol $90,000; cholesterol $210,000)	300,000	"	"
Net cost for 2,820,000 lb. of methyl esters . . . . . and the net cost per pound is 6.4 cents	180,400	per	annum.

It must be pointed out that the same building can house another 5 ton/day unit. Two such units could be handled by a slightly increased personnel. On the basis of a 10-ton daily output, the cost per pound is 5 cents. Note that distilled fatty acids are quoted at 14 cents per pound in tank load lots F.O.B. New York.

This estimate shows the importance of the byproducts, especially cholesterol. Herring, pilchard, and menhaden oils, which contain 1% cholesterol on the average, are thus of particular advantage. Cod liver oil is even more attractive since both cholesterol and vitamin A can be recovered.

Utilization of the Esters

Fraction I, I.V. 35

Although this material can be used as such, the removal of very small amounts of polyunsaturation which it contains may be necessary for some purposes. Fractional distillation of Fraction I yields colourless, odourless concentrates of individual esters in the range C_{10}-C_{16}.

Reduction of these esters according to the well established sodium process yields alcohols suitable for the manufacture of sulfonated detergents.

The same esters should find use in the manufacture of the new and very promising class of edible detergents, the sucrose fatty esters.

Heating the methyl esters at 200 degrees C. with glycerol in the presence of 0.1% $Ca(OH)_2$ readily converts them to monoglycerides.

The resulting colourless and stable monoglycerides are suitable as dispersing agents for food products, as raw materials for the production of modified monoglycerides, such as acetylated monoglycerides, and for many other uses.

Fraction II, I.V. 130

Heating of this material with glycerol and $Ca(OH)_2$ leads to very pale monoglycerides. These can be converted in the same reaction vessel to alkyd resins. The resulting alkyds are pale (3-4 of Gardner scale), and will air-dry with the addition of driers, or dry upon baking. Tougher and faster-drying films are obtained when pentaerythritol is substituted for glycerol.

Oxidation of Fraction II will furnish a mixture of easily separable mono- and dicarboxylic acids of medium chain length (from 8 to 12 C). This technique is now in commercial use in the U.S.A., starting from oils of vegetable origin. Use of Fraction II for this purpose should be of advantage in enlarging the range of acids obtainable. The yield of suitable acids is increased by selectively hydrogenating Fraction II in order to remove most of the polyunsaturation present. Fraction III, I.V. 250.

These esters react readily with polyalcohols when heated in the presence of a basic catalyst to produce polyesters. The reaction is the reverse of methanolysis.

Polyesters thus obtained are excellent drying oils. They can be used in paint formulation or as a raw material for varnishes.

Of particular interest are the polyesters made from pentaerythritol and the derived spar varnishes.

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EDMOND CLOUTIER, C.M.G., O.A., D.S.P.
QUEEN'S PRINTER AND CONTROLLER OF STATIONERY
OTTAWA, 1957

Reprinted from Chemistry and Industry, May 4, 1957, pp. 562—563

DEOXYRIBOSE-1 : 5-DIPHOSPHATE

By H. L. A. Tarr

Technological Station, Fisheries Research Board of Canada, Vancouver 2, B.C., Canada

Klenow[1] was the first to isolate and describe some of the chemical properties of ribose-1 : 5-diphosphate (R-1 : 5-P_2) which has now been prepared by chemical synthesis.[2] Later Klenow and Emberland[3] showed that deoxyribose-1-phosphate (DR-1-P) reacted much more rapidly than ribose-1-phosphate (R-1-P) in the phosphoribomutase catalysed reaction:

$$\text{R–1–P (DR–1–P)} + \text{R–1:5–P}_2 \rightleftharpoons \text{R–1:5–P}_2 + \text{R–5–P (DR–5–P)}$$

During a study of fish muscle purine riboside phosphorylase[4] it was found that the crude enzyme preparations possessed phosphoribomutase activity, and that incubation mixtures of equimolar quantities of di*cyclo*hexylammonium DR-1-P and tetra*cyclo*hexylammonium R-1 : 5-P_2 with this enzyme yielded six compounds, as indicated by paper chromatography,[1] and by colorimetric analyses of the eluates for deoxyribose,[6] ribose and acid labile[7] and comparatively acid stable[6] phosphorus. Two of these compounds were the starting compounds, and others were ribose-1-phosphate, deoxyribose-5-phosphate and ribose-5-phosphate. In addition, an apparently new compound which moved slightly faster on paper chromatograms[1] than did R-1 : 5-P_2 was detected. This compound gave a yellow zone with aniline hydrogen phthalate reagent,[5] quite distinct from the red colour given by R-1 : 5-P_2, and this fluoresced strongly in ultraviolet light. Enzyme reaction mixtures containing 50–75 μM of each of the starting compounds were incubated 3 hours at 30°C., and were then deproteinized with 50% propanol and subjected to preparative paper chromatography using Whatman 3 MM paper. The zones containing the new ester were eluted with ammonia water (pH 9·5–10), the solution concentrated to a small volume at low temperature and passed through a column containing a few ml. of Dowex 50, 200–400 mesh, cation exchange resin in the *cyclo*hexylamine form. The eluate and washings were evaporated to dryness in the cold and taken up in absolute methanol. On cautious addition of 3 volumes of diethyl ether a precipitate formed which, on drying for a few hours over phosphoric oxide in high vacuum, possessed properties which

suggested that it was tetra*cyclo*hexylammonium deoxyribose-1:5-diphosphate (M.W., 690·76). Analyses of chromatogram eluates from several reaction mixtures indicated that about 30–35% of the R-1 : 5-P_2 used appeared as the corresponding deoxyribose derivative. In a typical experiment 50 μM (35·3 mg.) of tetra*cyclo*hexylammonium R-1 : 5-P_2 yielded 12 mg. of tetra*cyclo*hexylammonium DR-1 : 5-P_2 which gave the following analyses (per cent. of theoretical) : deoxyribose,[6] 100·5%; phosphorus labile in 100 minutes at pH 4·0[7] (measures DR-1-P phosphorus), 96·5%; and phosphorus labile in 60 minutes in 1N HCl at 100°C.[6] (measures both DR-1-P and DR-5-P phosphorus), 98%. No orthophosphate[7] was detected in this preparation. It is concluded that the following reaction occurs:

$$\text{DR–1–P} + \text{R–1:5–P}_2 \rightleftharpoons \text{DR–1:5–P}_2 + \text{R–5–P}$$

This work was made possible by donation of generous supplies of R-1 : 5-P_2 by Drs. Tener and Khorana.

Received March 27, 1957

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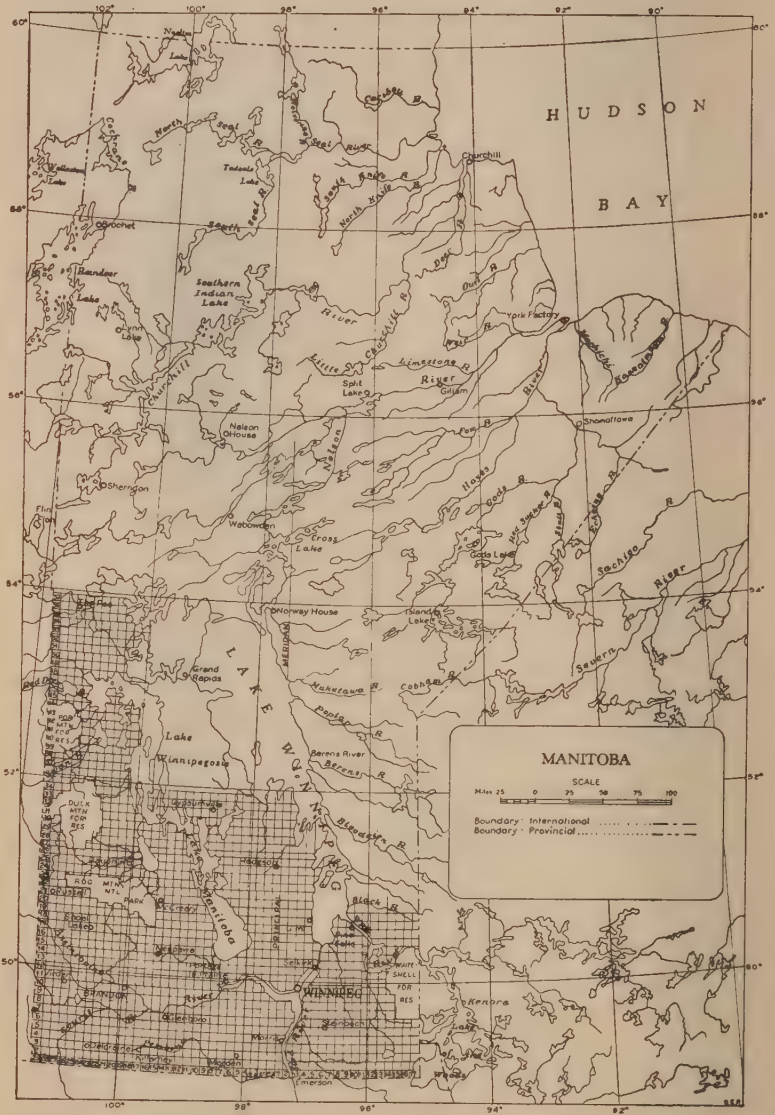
Supplement to Hinks' "THE FISHES OF MANITOBA"

by

J. J. KELEHER
and
B. KOOYMAN

FRB No. 481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Sachigo River
Severn
Berens River
Poplar R.
Cobham R.
Manigotagan
Pine Falls
Selkirk
Gimli
Riverton
Beausejour
Kenora
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Brandon
Portage la Prairie
Dauphin
Swan River
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Sherridon
Wabowden
Thompson
Gillam
Churchill
Nelson House
Split Lake
York Factory
Shamattawa

Supplement to Hinks' "The Fishes of Manitoba"[1]

by J. J. Keleher[2] and B. Kooyman[3]

INTRODUCTION

Numerous requests for copies of "The Fishes of Manitoba" by David Hinks, now out of print, indicate continuing need for a text on Manitoba's ichthyofauna. To prepare an adequate successor to Hinks' book at this time is not feasible, yet to reissue it solely in its original form would be to ignore the results of that "spirit of enquiry" engendered by the book itself.

In the 14 years since "The Fishes of Manitoba" was published, there have been changes in the scientific and common names of some fishes. In addition, knowledge concerning the biology of many Manitoba fishes has been considerably clarified. In order to note these advancements, especially in nomenclature and distribution, a supplement, concerned only with the freshwater fishes, has been prepared for use with the original text. References to subsequent Manitoba studies in fishery biology have been included.

NOMENCLATURE

Within the last six years a tendency, advocated initially by Dr. R. M. Bailey of the University of Michigan, to consolidate genera of North American freshwater fishes has been evident. The suggested changes have not been incorporated throughout this supplement since it would make reference to Hinks' text difficult. However, the genera which have been affected to date are recorded in Table 1.

TABLE I. PROPOSED CHANGES IN GENERIC NAMES

Name in Hinks	Change	Reference
Cristivomer	*Salvelinus*	41 but see 54
Amphiodon	*Hiodon*	2
Leucichthys	*Coregonus*	19, 40
Prosopium	*Coregonus*	19 but see 55
Megastomatobus	*Ictiobus*	2
Hyborhynchus	*Pimephales*	2, 11
Pfrille	*Chrosomus*	52
Couesius	*Hybopsis*	2
Nocomis	*Hybopsis*	2
Platygobio	*Hybopsis*	2
Margariscus	*Semotilus*	52
Ameiurus	*Ictalurus*	52
Schilbeodes	*Noturus*	52
Hadropterus	*Percina*	6
Imostoma	*Hadropterus*	2
Poecilichthys	*Etheostoma*	2
Boleosoma	*Etheostoma*	2
Huro	*Micropterus*	5
Triglopsis	*Myoxocephalus*	55

Differences from Hinks' usage in the spelling of the specific names for the following fishes will be noted in this supplement: *Salmo gairdneri, Leucichthys artedii, Catostomus commersoni, Hybopsis storeriana, Pomoxis nigromaculatus, Micropterus dolomieui, Cottus bairdi* and *Triglopsis thompsoni*. These, with the exception of *H.*

[1]Published in May, 1957, by the Department of Mines and Natural Resources, Province of Manitoba.

[2]Biologist, Fisheries Research Board of Canada, Biological Station, Winnipeg.
[3]Fishery Biologist, Department of Mines and Natural Resources, Province of Manitoba.

storeriana[28], are the result of anticipated changes in the International Rules of Zoological Nomenclature.

The surname(s) following a scientific name is called the "authority citation". Enclosing it in parentheses shows that the species has been transferred from the original genus in which it was placed by the author. The following changes should be made in Hinks' text: *Ictiobus bubalus* (Rafinesque), *Erimyzon sucetta* (Lacépède), *Notropis umbratilis* (Girard), *Rhinichthys cataractae* (Valenciennes) and *Esox masquinongy* Mitchell.

A desirable standardization of common names of fishes is being attempted by the American Fisheries Society. The recommendations were initially published[10] in 1948 and amended since then in the 1951, 1952, and 1953 issues of the journal, "Transactions of the American Fisheries Society". While we have used the common names indicated in these publications, some species are not listed in them; hence the source for their names is indicated. The reader is urged to use these common names so that eventually the confusing use of several different local names for the same species of fish will disappear.

DISTRIBUTION

As knowledge of the distribution of fishes in Manitoba is still incomplete, statements modifying Hinks' remarks on distribution purposely have been very specific so as to indicate the present extent of our knowledge. Where such statements are not supported by literature citations or specimens listed in the appendix they are based upon sight records considered reliable by the authors. Generalizations on distribution are often a hindrance because they tend not only to discourage the publication of actually new information but also, if they become accepted, to induce errors which are difficult to correct.

Cataloguing the distribution of a species within a political unit is artificial. Only by delineating its occurrence on a continental or world basis can a full appreciation of its ecology be gained. No attempt has been made to supply the reader with the available published information since it may be found in such books as "Fishes of the Great Lakes Region"[30].

Manitoba's geographical position seems to account for some interesting distributions. According to published records, this Province is the western limit of natural distribution in Canada for 17 species of fish: *Ichthyomyzon castaneus, I. unicuspis, Salvelinus fontinalis, Semotilus atromaculatus, Nocomis biguttatus, Hybopsis storeriana, Rhinichthys atratulus, Notropis rubellus, Notropis volucellus, Hyborhynchus notatus, Schilbeodes gyrinus, Umbra limi, Fundulus diaphanus, Imostoma shumardi, Lepomis gibbosus, Pomoxis nigromaculatus, and Amblоplites rupestris.* Our original list has been reduced by recent Saskatchewan records[1]. Similarly, Manitoba is the eastern limit in Canada for three other species: *Platygobio gracilis, Notropis blennius* and *Thymallus arcticus.* The northern limit of some species also may be found in this Province.

Since distributional limits often reveal the ecological factors responsible for the restriction of further dispersal, it is evident that distributional information which may appear to be only of local interest is really of much wider importance. The Fisheries Branch of the Department of Mines and Natural Resources therefore will be most willing to assist any person in preparing a reliable record of new occurrences so that a scientifically acceptable contribution can be made.

DISCUSSION OF INDIVIDUAL SPECIES

Ichthyomyzon castaneus — Chestnut lamprey, p. 14.

The chestnut lamprey has been reported from lakes Manitoba[29] and Winnipeg[32] and from the Red and Assiniboine rivers[29]. Hinks' record from the Winnipeg River should be verified since it is within the probable distribution of the silver lamprey.

Ichthyomyzon unicuspis—Silver lamprey.

This species, rarely collected in Manitoba, should be added to our faunal list. It can be distinguished from the chestnut lamprey by its unicuspid rather than bicuspid circumoral teeth. Manitoban records have been

limited, so far, to the lower Nelson[15, 29] and Hayes rivers[29].

Acipenser fulvescens—Lake sturgeon, p. 15.

Distribution in the lower regions of the Hudson Bay drainage system includes the Seal River which flows into the Bay north of Churchill. Sturgeon are still taken on the Assiniboine River as far west as Brandon.

Amphiodon alosoides—Goldeye, p. 19.

This species is found in the Red Deer River emptying into Lake Winnipegosis and is taken in commercial quantities (approximately 25,000 pounds annually) in the Churchill River system above Southern Indian Lake.

Hiodon tergisus—Mooneye, p. 19.

This species is found in Lake Winnipeg and occurs in the Nelson River at least down to Sipiwesk Lake. It has been collected from the Saskatchewan River drainage in Manitoba.

Cristivomer namaycush—Lake trout, p. 22.

This member of the char group occurs naturally in all the deeper lakes lying within the Precambrian Shield area of Manitoba which includes the Whiteshell Forest Reserve, the region east of Lake Winnipeg and most of the area north of the 54th parallel of latitude. Its range has been artificially extended to Childs, Laurie, Glad and East Blue lakes in the Duck Mountain Forest Reserve, Whitefish Lake in the Porcupine Mountain Forest Reserve and Clear Lake [42].

NOTE: The "splake", an artificial hybrid between lake trout and eastern brook trout, has been cultured in Manitoba and stocked in Hunt Lake (Township 9, Range 17E) in 1955 and 1956. The appearance of some hybrids has been described[45, 50].

Salvelinus alpinus—Arctic char, p. 24.

In Manitoba this char is found along the Hudson Bay coast and in the lower reaches of the waters flowing into the Bay[49]. It has been taken rarely as far south as the mouth of the Nelson River but becomes common northward from Churchill.

Salvelinus fontinalis—Eastern brook trout, p. 25.

The northwestern limit of the natural range of this char in North America occurs in Manitoba. The brook trout is known now to have an almost continuous distribution in suitable streams along the coast of James Bay [44] and the west coast of Hudson Bay as far north as Sam Creek near the mouth of the Nelson River. North of this the occurrence seemingly is discontinuous but it is found in the lower parts of the Churchill, South Knife, North Knife, and Seal rivers.

The species is abundant in the Gods River system as far south as Island Lake River and occurs in such tributaries as the Red Sucker, Stull and Echoing rivers. In the Nelson River it has been found upstream as far as Kettle Rapids[14].

The brook trout has had its range extended in the Province by successful introductions to streams originating in the Duck Mountain and Porcupine Mountain Forest Reserves. Trout species did not occur naturally in these streams. See NOTE under lake trout regarding the hybrid called "splake".

Salmo gairdneri — Rainbow trout, p. 26.

This member of the true trout group is not native to Manitoba but has a considerable distribution in the Province through fish cultural efforts. It has been successfully stocked in lakes which have had their original populations of fish eradicated by use of toxicants[9] and has also become established in a number of streams originating in the Duck Mountain and Porcupine Mountain Forest Reserves where no salmonids occurred naturally. Its range is being extended further each year.

Salmo trutta—Brown trout, p. 26.

The brown trout is an European fish that has been stocked in selected waters of the Province. It is known to have survived in Telford Pond.

Leucichthys spp.—Ciscoes, p. 27 ff.

The number of species of ciscoes occurring in Manitoba and their correct scientific names are at present under study. The difficulty in their classification arises in that many characters used for identification vary with the age and growth rate of the fish and probably the environmental conditions in which it lives.

Support for the occurrence of four species of ciscoes in Lake Winnipeg has been presented[31] but the presence of a fifth has been questioned[15]. A new species, *Leucichthys churchillensis* has been described from the Churchill River[21] but it may not be valid.

Thymallus arcticus—Arctic grayling, p. 35.

Thymallus signifer has been regarded as a subspecies of the Siberian fish[55]. Its range includes all of the major Hudson Bay coastal streams and their tributaries from the Owl River northward into the Northwest Territories. It is also found far inland in such northern streams as the Seal, Wolverine, and Cochrane rivers.

Carpiodes cyprinus — Quillback carpsucker, p. 39.

The quillback carpsucker has been collected in the Winnipeg River, Lake Manitoba and in Lake Winnipeg to Pigeon Bay.

On account of Hinks' reference to the synonymy of *C. cyprinus*, it should be noted that *C. velifer* (Rafinesque) is a valid species [26]. None of the Manitoba *Carpiodes* that we have examined appear to be referable to this species. Although unrecorded from North Dakota, it does occur in the Mississippi River drainage of southeastern Minnesota[4].

Hypentelium nigricans—Hog sucker, p. 40.

The records for the hog sucker from the Lake of the Woods were based on a misidentification of *Catostomus commersoni*[27]. Until actually collected, the hog sucker should be omitted from the Manitoba check list.

Moxostoma rubreques — Greater redhorse, p. 41.

M. rubreques Hubbs is a synonym of *M. valenciennesi* Jordan[40]. The range of this species probably does not include Manitoba. It is found in the Mississippi River drainage of Minnesota and Wisconsin[17]. The illustration of *M. rubreques* in "The Fishes of Manitoba" was regarded[38] as that of *M. aureolum*.

Moxostoma aureolum—Northern redhorse, p. 42.

The northern redhorse has been found in lakes Winnipeg, Manitoba, and Little Playgreen. It also occurs in the Red and Winnipeg River systems and in the western portion of the Lake Winnipegosis drainage.

Moxostoma anisurum — Silver redhorse, p. 42.

The northern limit of distribution of the silver redhorse is in Manitoba. It has been taken in the Whitemouth, Red[18], Shell and Woody rivers as well as in lakes Winnipeg and Kelsey.

Erimyzon sucetta—Lake chubsucker, p. 43.

No specimens are available to confirm its presence in Manitoba. One record of occurrence[7] does not necessarily apply and another from an adjoining region[22] apparently has not been accepted[17, 30].

Cyprinus carpio—Carp, p. 45.

The distribution of the carp is extending in the Province[16]. A specimen was examined from Lake Manitoba in 1947, Lake Dauphin in 1954, Dawson Bay on Lake Winnipegosis in 1955 and Whitemud Falls (54° 45′N. 97° 53′W) on the upper Nelson River in 1956. This species has been collected in the Assiniboine River at Brandon and at Kamsack, Saskatchewan[1].

Campostoma anomalum — Stoneroller, p. 47.

The presence of the stoneroller in the Province has yet to be verified. The North Dakota record[22] is for the Missouri River drainage.

Hyborhynchus notatus — Bluntnose minnow, p. 48.

A rare Manitoba minnow because it has been found only at three localities: Winnipeg[20], St. Andrews Locks on the Red River, and Echo Lake[33].

Hybognathus nuchalis—Silvery minnow[36], p. 48.

No specimens have been obtained by us and it is not known from the Red River drainage[3]. One record[53] originated from a statement attributed to D. S. Jordan, "Upper Missouri and Red River of the North". Bajkov's record[7] does not specifically refer to Manitoba.

Hybognathus hankinsoni — Brassy minnow[30].

The brassy minnow was omitted by Hinks but has been recorded recently[3, 33].

Chrosomus eos—Redbelly dace, p. 49.

This species has been taken only in the Whiteshell Forest Reserve.

Pfrille neogaea — Finescale dace[30], p. 49.

This dace also has been collected only in the Whiteshell Forest Reserve.

Notemigonus crysoleucas — Golden shiner, p. 49.

The golden shiner has been collected in the Whiteshell Forest Reserve, Lake Manitoba, and a tributary of Lake Winnipegosis.

Notropis rubellus—Rosyface shiner[30], p. 52.

Although regarded by Hinks as only of possible occurrence in Manitoba, this shiner has been taken in the Winnipeg River system[33].

Notropis cornutus — Common shiner, p. 52.

Our records for Manitoba include the Whitemouth and Cypress rivers, and some of the western tributaries of Lake Dauphin, Swan Lake[33], and the Red River.

Notropis heterolepis — Blacknose shiner[30], p. 53.

The blacknose shiner is found in many lakes and streams of the Whiteshell Forest Reserve. It also occurs in Lake Manitoba, in smaller lakes of the Duck Mountain Forest Reserve and south of the Riding Mountain National Park and a tributary of the Red River. It has been taken as far north as latitude 55°.

Notropis volucellus — Mimic shiner, p. 53.

Specimens identified as the mimic shiner have been taken in the Winnipeg River system and in a Lake Winnipegosis tributary. The recorded northern limit is in Fishing Lake [33].

Notropis deliciosus — Sand shiner, p. 53.

This species has been identified in collections from the Red and Assiniboine River drainages. It occurs as far north as the Mossy River at Winnipegosis[33].

Notropis blennius — River shiner[30], p. 53.

Although known from the Saskatchewan River system[15], our records, with two exceptions, are confined to the immediate vicinity of the Red River.

Notropis umbratilis—Redfin shiner[30], p. 54.

The Lake of the Woods record cited by Hinks has been shown to be in error[27].

Rhinichthys cataractae — Longnose dace, p. 55.

This minnow is common and widely distributed in Manitoba as these records will indicate: Winnipeg, Red, Assiniboine, Saskatchewan, Nelson, Hayes, Gods, and Churchill River systems, tributaries of lakes Dauphin, Winnipegosis and Swan, as well as Lake Winnipeg[32] and Clear Lake[42].

Rhinichthys atratulus — Blacknose dace, p. 55.

This fish has been found in the Pembina, Whitemud, and Assiniboine River systems and in tributary streams of lakes Dauphin, Winnipegosis, and Swan. The blacknose dace has not been collected in Manitoba east of La Riviere (98° 43′W).

Couesius plumbeus—Lake chub, p. 55.

Specimens of the lake chub have been collected at West Hawk Lake, in the Saskatchewan, Gods, Nelson, and Churchill River drainages and north to South Knife Lake[33].

Hybopsis storeriana — Silver chub, p. 56.

Records are confined to the Assiniboine River at Winnipeg and the Red River system. The known northern limit has been extended to include St. Andrews Locks.

Nocomis biguttatus—Hornyhead chub, p. 56.

This chub, so far, has been found only in southeastern Manitoba[33].

Margariscus margarita — Pearl dace, p. 56.

This dace has been found in single locations from the drainage systems of the Pembina, Assiniboine, Winnipeg, Gods, and Owl rivers as well as in one lake of the Whiteshell Forest Reserve. It occurs also in a number of streams flowing from the Duck Mountain and Porcupine Mountain Forest Reserves, but specimens are taken only rarely.

Semotilus atromaculatus—Creek chub, p. 57.

The first positive record of occurrenee was established by Kooyman's 1949 collection from the Little Pembina River. It has been collected in the western tributaries of lakes Manitoba, Dauphin, Swan, and Winnipegosis, and tributaries of the Red and Assiniboine rivers but not east of Dominion City.

Platygobio gracilis — Flathead chub, p. 57.

This species has been taken in Kelsey Lake (Township 54, Range 25W).

Ictalurus punctatus—Channel catfish, p. 58.

The channel catfish should not be called *Ictaluris lacustris* (Walbaum) because the description associated with *lacustris* was derived from a burbot[47]. This conclusion also was reached independently by Legendre[40].

It has been taken in the southern end of Lake Manitoba.

Ameiurus melas — Black bullhead, p. 59.

The black bullhead has been taken in shallow lakes of southern Manitoba.

Ameiurus nebulosus—Brown bullhead, p. 59.

The brown bullhead is common in the Red River system and has been taken in the Whiteshell Forest Reserve.

Schilbeodes gyrinus — Tadpole madtom[30], p. 61.

The use of the specific name, *mollis*, for this species, appears not to be warranted[52].

The occurrence of this small catfish in the Red River has been verified and its known distribution extended northward to central Lake Winnipeg[32].

Fundulus diaphanus—Banded killifish.

The first Manitoba record of this eastern species was noted by R. K. Stewart-Hay[51].

Umbra limi — Central mudminnow, p. 64.

This mudminnow occurs in the Red and Winnipeg River drainages.

Stizostedion vitreum glaucum — Blue walleye, p. 69.

The statement[25] that this subspecies occurs in the eastern portion of Lake Winnipeg has not been confirmed by the collection of specimens. It should be omitted from the Manitoba check list.

Percina caprodes—Log perch, p. 72.

The log perch has been found in the Winnipeg River system, Lake Dauphin, Whitefish Lake, Red Deer River, and in waters east of Lake Winnipeg. In northern Manitoba (north of the 54th parallel of latitude) it occurs at least to Hunter Lake.

Hadropterus maculatus — Blackside darter[30], p. 72.

Records for the blackside darter come from two separate areas—Winnipeg, Red, and Assiniboine River drainages and several tributaries of Swan Lake.

Poecilichthys exilis — Iowa darter[30], p. 73.

The distribution of this darter extends northward at least to the Saskatchewan River near The Pas.

Boleosoma nigrum — Johnny darter, p. 73.

The Johnny darter is collected more frequently than the Iowa darter and it apparently ranges into more northern waters being found at least to Southern Indian Lake.

Imostoma shumardi—River darter[30], p. 73.

The river darter appears to be sparsely distributed in Manitoba. It has been reported from the Red River[18], Winnipeg River[25], Mukutawa* River[32], and at Gladstone Heights*[32]. Subsequently, it has been collected at several more localities along Lake Winnipeg and in Lake Dauphin, Sipiwesk Lake, and the Red Deer River.

FOOTNOTE:

*Throughout the paper cited (i.e. 32) the name "Mukutawa" was spelled incorrectly as "Mukatawa". The map name "Bull Head" was used in place of the local name "Calder's Dock". "Gladstone Heights" would be a more suitable name to avoid confusion with another collecting site.

Pomoxis nigromaculatus—Black crappie, p. 74.

The black crappie is found only infrequently in Manitoba. It has been obtained from the Winnipeg River, the southern portion of Lake Winnipeg, and Minnewasta Lake. The last is an accidental introduction.

Ambloplites rupestris — Rock bass, p. 75.

This fish is distributed across eastern Canada to Manitoba. In our Province specimens have been secured only as far west as the Minnedosa River and as far north as Mukutawa River.

Lepomis gibbosus—Pumpkinseed.

The pumpkinseed has been recorded from two places in southeastern Manitoba, Telford Pond and Burton Lake.

Micropterus dolomieui — Smallmouth bass, p. 77.

The smallmouth bass is not native to Manitoba. Its introduction to Lake of the Woods in the early 1900's[44], allowed further extension of its range into Manitoba via the Winnipeg River system. The range of this bass has been extended in the Province through migration and by transplanting to include the Winnipeg River, the lower reaches of the Whiteshell River, West Hawk, Caddy, Falcon and Shoal lakes, all in southeastern Manitoba. The most northern occurrence of this species in Canada is in Lake Athapapuskow at 54° 41′ north latitude and 101° 40′ west longitude where it was introduced in 1940 and continues to survive.

Huro salmoides — Largemouth bass, p. 78.

This bass is found in two of Manitoba's lakes, Minnewasta and Silver Beach (Township 21, Range 26 W.) and a pond at Fort Whyte near Winnipeg as an introduced species. Plantings in other waters do not seem to have survived.

Aplodinotus grunniens — Freshwater drum, p. 80.

The recorded northern limit[46] of distribution is the mouth of the Limestone River which is at 56° 31′ north latitude.

Cottus ricei—Spoonhead sculpin, p. 81.

Specimens have been collected from only a few localities in Manitoba: West Hawk Lake, Bull Head, Mukutawa River[32], Saskatchewan River, and near York Factory.

Cottus cognatus — Slimy sculpin[44], p. 81.

This species is distributed from Labrador to Alaska[15]. It apparently replaces *C. bairdi* in northern Manitoba. Our most northern record for *C. cognatus* is at 58° 33′ north latitude. In southern Manitoba it is uncommon but has been collected from Armit Lake, Steeprock River, Lake Winnipeg, Clear Lake[42], Winnipeg River and a coldwater stream flowing into George Lake.

Cottus bairdi — Mottled sculpin[44], p. 81.

This sculpin is the usual species in southern Manitoba, being found in Lake Winnipeg[32] and abundantly in waters of the Whiteshell Forest Reserve. There are also two records from streams in the Duck Mountain Forest Reserve.

Triglopsis thompsoni—Deepwater sculpin[30], p. 81.

With the exception of Reindeer Lake[43] on the Manitoba-Saskatchewan boundary, the deepwater sculpin apparently has not been collected from any Manitoba lake.

Eucalia inconstans — Brook stickleback, p. 83.

The brook stickleback is very abundant in southern Manitoba. It occurs at least to streams near Churchill.

Pungitius pungitius — Ninespine stickleback, p. 83.

The ninespine stickleback has a more discontinuous distribution in southern Manitoba than the brook stickleback. It occurs in the Assiniboine River, West Hawk Lake, Lake Winnipeg[32], Aikens Lake, Armit Lake, and the Red Deer River. In collections from northern Manitoba it occurs more frequently than the brook stickleback.

Lota lota—Burbot, p. 84.

The burbot is generally considered to be a fish of lakes and large streams but young specimens have been found in many small rapid-flowing streams throughout the Province.

ACKNOWLEDGMENTS

The authors, on behalf of the Department of Mines and Natural Resources, wish to express their appreciation to the Royal Ontario Museum at Toronto for permission to publish Museum records on material from departmental surveys in Manitoba. If it were not for the interest of Dr. J. R. Dymond, former director of the Museum, and Dr. W. B. Scott, present curator of the Department of Ichthyology and Herpetology, much of the information would not be available for this supplement.

The authors are particularly indebted to Dr. Scott for the identifications on many departmental collections and for comments on the manuscript. Dr. K. F. Lagler also offered suggestions for improvement of a draft of the manuscript.

The assistance of the following persons in making collections is acknowledged: H. J. Burrell, K. C. Dey, R. D. Lyon, T. A. Paddock, R. S. Williams and Gloria Keleher. Some records from the following collectors have been used: Dr. I. G. Arnason, Mr. J. Bodnar, Mr. G. E. Butler, Dr. K. H. Doan, Mr. C. W. Douglas, Mr. T. Halgren, Mr. L. C. Hewson, Dr. P. M. Jackin, Dr. J. A. McLeod, Mr. L. T. S. Norris-Elye, Mr. K. G. Roberts, Dr. W. M. Sprules, Mr. R. K. Stewart-Hay, Mr. L. A. Sunde and Mr. C. H. Watson.

Mrs. Catherine Kostelnuk assisted in preparing the manuscript. Mr. D. E. Perry prepared the map. Particular thanks are extended to Miss S. Helen Josephson and Miss Diana J. Moroz who so willingly prepared the many drafts inevitable under a joint authorship.

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APPENDIX

SELECTED LOCALITY RECORDS SUPPORTING DISTRIBUTIONAL STATEMENTS

The position of a locality record is given either by section, township and range (east or west of the Principal Meridian located at 97° 28′ of west longitude) or in degrees and minutes of north latitude and west longitude. Collector's initials follow each record.

Specimens are deposited in the collections of either the Royal Ontario Museum, Toronto, or the Fisheries Research Board Biological Station, Winnipeg.

Amphiodon alosoides

Baptising Creek (31, 52, 22W) W.S.

Hiodon tergisus

Baptising Creek (31, 52, 22W) W.S.

Salvelinus fontinalis

Kanuchuan Rapids (54 22; 94 49) B.K.
Gods River (54 54; 94 04) B.K.
Bad River (56 37; 94 26) B.K.
trib. Weir River (56 46; 94 27) B.K.

Thymallus signifer

Silcox Creek (57 09; 94 10) B.K.

Carpiodes cyprinus

vicinity Delta (14, 14, 07W) J.K.
Great Falls (27, 17, 11E) J.K.
Pigeon Bay (—, 38, 03E) K.R.

Moxostoma aureolum

Birch River (11, 08, 13E) J. K.
La Salle River (20, 09, 03E) J.K.
vicinity Langruth (—, 16, 08W) J.K.
Bull Head (25, 30, 05E) L.H.
Swan River (21, 36, 27W) J.K.
Red Deer River (21, 45, 25W) W.S.
vic. Norway House (09, 58, 03W) J.K.

Moxostoma anisurum

Elma (32, 10, 12E) J.K.
vic. Winnipeg Beach (34, 17, 04E) L.H.
Shell River (08, 26, 28W) J.K.
Woody River (27, 37, 27W) J.K.
Pigeon Bay (—, 38, 03E) K.R.
Kelsey Lake (—, 54, 25W) W.S.

Cyprinus carpio

Brandon (19, 10, 18W) J.K.
Minnedosa River (34, 10, 20W) J.K.

Hyborhynchus notatus

Red River (02, 13, 04E) L.N.

Chrosomos eos

Telford Pond (20, 10, 16E) B.K.
Rennie River (24, 10, 14E) J.K.
Hanson Creek (15, 10, 16E) J.K.

Pfrille neogaea

Telford Pond (20, 10, 16E) B.K.
Rennie River (24, 10, 14E) J.K.
Brereton Lake (—, 11, 15E) J.M.

Notemigonus crysoleucas

Tie Creek (20, 14, 15E) B.K.
Burton Lake (02, 16, 15E) B.K.
vic. Whitemud River (—, 15, 08W) C.W.
Winnipegosis (10, 31, 18W) G.B.

Notropis cornutus

Little Pembina R. (28, 02, 18W) B.K.
La Riviere (19, 03, 09W) J.K.
Cypress River (08, 07, 12W) J.K.
Whitemouth River (36, 11, 11E) J.K.
Turtle River (30, 22, 15W) J.K.
Vermilion River (10, 25, 19W) J.K.
Valley River (14, 26, 26W) B.K.
Shell River (—, 30, 27W) B.K.
Winnipegosis (10, 31, 18W) G.B.
Roaring River (05, 34, 27W) B.K.

Notropis heterolepis

Caddy Lake (—, 10, 17E) B.K.
Whiteshell River (10, 12, 16E) B.K.
Wavey Creek (32, 14, 03E) J.K.
vic. Whitemud River (—, 15, 08W) C.W.
Crawford Lake (02, 18, 21W) B.K.
Persse Lake (36, 29, 29W) L.S.
Chataway Creek (54 32; 94 17) B.K.
Sipiwesk Lake (55 05; 97 35) L.S.

Notropis volucellus

Eleanor Lake (06, 14, 13E) J.K.
Tie Creek (20, 14, 15E) B.K.
Woody River (27, 37, 27W) J.K.

Notropis deliciosus

Roseau River (20, 02, 03E) J.K.
Pembina River (19, 03, 09W) J.K.
Assiniboine River (—, 10, 02E) J.K.
Minnedosa River (34, 10, 20W) J.K.
St. Andrews Locks (11, 13, 04E) G.B.

Notropis blennius

Dominion City (20, 02, 03E) J.K.
Morris (03, 05, 01E) J.K.
St. Norbert (20, 09, 03E) J.K.
Black Bear Island (25, 32, 04E) J.K.
Woody River (34, 36, 29W) B.K.

Rhinichthys cataractae

Dominion City (20, 02, 03E) J.K.
Pembina River (19, 03, 09W) J.K.
Tie Creek (20, 14, 15E) B.K.
Seven Sisters Falls (27, 13, 11E) G.B.
Souris River (34, 07, 21W) J.K.
Minnedosa River (34, 10, 20W) J.K.
Vermilion River (10, 24, 24W) J.K.
Valley River (14, 26, 26W) B.K.
Pine River (32, 32, 23W) B.K.
Swan River (21, 36, 27W) J.K.
Birch River (26, 39, 26W) J.K.
Red Deer River (21, 45, 25W) W.S.
Saskatchewan River (31, 52, 22W) W.S.
Kanuchuan Rapids (54 22; 94 49) B.K.
Chataway Creek (54 32; 94 17) B.K.
Gods River (55 06; 93 37) B.K.
Limestone River (56 31; 94 07) B.K.
trib. Weir River (56 48; 94 11) B.K.
trib. Hayes River (57 00; 92 18) K.D.
trib. Herriot Cr. (58 33; 94 22) B.K.

Rhinichthys atratulus

Mary Jane Creek (30, 03, 09W) J.K.
Cypress River (08, 07, 12W) J.K.
Eden (22, 16, 15W) J.K.
Wilson River (14, 25, 21W) K.D.
Drifting River (05, 27, 21W) K.D.
Shell River (08, 26, 27W) J.K.
Pine River (32, 32, 23W) B.K.
Roaring River (05, 34, 27W) B.K.
Woody River (34, 36, 29W) B.K.
Birch River (26, 39, 26W) J.K.

Couesius plumbeus

Indian Bay Cr. (13, 09, 17E) B.K.
Big Eddy (24, 56, 27W) W.S.
Chataway Creek (54 32; 94 17) B.K.

Gods River (54 51; 94 05) B.K.
Limestone River (56 37; 94 27) B.K.
S. Indian Lake (57 05; 98 34) B.K.
Silcox Creek (57 09; 94 10) B.K.

Hybopsis storeriana

La Salle River (20, 09, 03E) J.K.
Assiniboine River (—, 10, 02E) J.K.
St. Andrews Locks (11, 13, 04E) B.K.

Margariscus margarita

Little Pembina R. (28, 02, 18W) B.K.
Camp Lake (03, 09, 17E) G.B.
Bog River (15, 13, 09E) J.B.
Big Boggy Creek (02, 27, 29W) J.K.
Valley River (14, 26, 26W) B.K.
Pine River (32, 32, 23W) B.K.
Roaring River (05, 34, 27W) B.K.
Woody River (34, 36, 29W) B.K.
Birch River (34, 39, 26W) B.K.
Chataway Lake (54 32; 94 20) B.K.

Semotilus atromaculatus

Roseau River (20, 02, 03E) J.K.
Little Pembina R. (28, 02, 18W) B.K.
Cypress River (08, 07, 22W) J.K.
Eden (22, 16, 15W) J.K.
Turtle River (07, 21, 15W) J.K.
Valley River (14, 26, 26W) B.K.
Big Boggy Creek (02, 27, 29W) J.K.
Roaring River (05, 34, 27W) B.K.
Duck River (26, 35, 23W) J.K.
Birch River (26, 39, 26W) J.K.

Ameiurus melas

Rock Lake (15, 03, 13W) B.K.
Norris Lake (29, 17, 01E) L.S.

Ameiurus nebulosus

Pembina River (25, 03, 10E) G.B.
Ryerson Creek (21, 16, 17E) G.B.
Icelandic River (21, 23, 03E) J.K.

Umbra limi

Rennie River (24, 10, 14E) J.K.
La Salle River (02, 11, 03W) J.K.
Whiteshell River (09, 12, 16E) B.K.
Tie Creek (20, 14, 15E) B.K.

Percina caprodes

Whitemouth River (36, 11, 11E) J.K.
McMurray Creek (04, 15, 15E) B.K.
Dauphin Beach (05, 25, 27W) R.S.
Whitefish Lake (08, 39, 29W) R.S.
Red Deer River (21, 45, 25W) W.S.
Family Lake (—, 34, 15E) G.B.
Hunter Lake (56 37; 100 54) C.D.

Hadropterus maculatus

Joubert Creek (34, 05, 04E) J.K.
Birch River (11, 08, 13E) J.K.
Minnedosa River (34, 10, 20W) J.K.
Whitemouth River (36, 11, 11E) J.K.
Wavey Creek (09, 15, 04E) J.K.
Shell River (—, 30, 27W) B.K.
Roaring River (05, 34, 27W) B.K.
Woody River (27, 37, 27W) J.K.
Swan River (21, 36, 27W) J.K.
Birch River (34, 39, 26W) B.K.

Poecilichthys exilis

Big Eddy (24, 56, 27W) W.S.

Boleosoma nigrum

S. Indian Lake (57 10; 98 40) B.K.

Imostoma shumardi

Lake Dauphin (05, 25, 27W) R.S.
Gull Harbour (25, 25, 06E) J.K.
Berens River (—, 39, 03E) B.K.
Red Deer River (17, 45, 25W) J.K.
Spider Islands (—, 52, 02E) B.K.
Sipiwesk Lake (55 05; 97 35) L.S.

Pomoxis nigromaculatus

Minnewasta Lake (36, 02, 06W) G.A.
Ryerson Creek (21, 16, 17E) G.B.
off Black River (36, 21, 03E) T.H.

Ambloplites rupestris

Camp Lake (03, 09, 17E) G.B.
Elma (32, 10, 12E) J.K.
Dorothy Lake (04, 14, 13E) J.K.
Wavey Creek (32, 14, 03E) J.K.
Minnedosa River (13, 15, 18W) G.A.
Sasaginnigak Lake (—, 30, 13E) G.B.
Mukutawa River (29, 48, 01E) K.R.

Lepomis gibbosus

Telford Pond (20, 10, 16E) K.D.
Burton Lake (02, 16, 15E) B.K.

Cottus ricei

West Hawk Lake (—, 09, 17E) K.D.
Bull Head (31, 30, 06E) J.K.
Big Eddy (24, 56, 27W) W.S.
Blackwater Cr. (56 55; 92 35) K.D.

Cottus cognatus

McMurray Creek (04, 15, 15E) B.K.
Seven Sisters Falls (27, 13, 11E) G.B.
Bull Head (31, 30, 06E) J.K.
Sturgeon Bay (36, 35, 05W) B.K.
Armit Lake (—, 42, 29W) R.S.
Steeprock River (23, 43, 26W) B.K.
Kanuchuan Rapids (54 22; 94 49) B.K.
Gods River (54 51; 94 05) B.K.
McCallum Lake (56 05; 101 45) B.K.
Limestone River (56 32; 94 08) B.K.
Blackwater Creek (56 55; 92 35) K.D.
trib. Herriot Cr. (58 33; 94 22) B.K.

Cottus bairdi

West Hawk Lake (26, 09, 17E) B.K.
Crowduck Lake (30, 13, 17E) B.K.
Tie Creek (20, 14, 15E) B.K.
Pine River (32, 32, 23W) B.K.
Duck River (26, 35, 23W) J.K.

Eucalia inconstans

Insectary stream (58 45; 94 09) P.J.

Pungitius pungitius

West Hawk Lake (16, 09, 17E) B.K.
Assiniboine River (—, 10, 02E) J.K.
Red Deer River (21, 45, 25W) W.S.
Eden Lake (56 38; 100 15) B.K.
N. Indian Lake (57 20; 97 20) B.K.
South Knife Lake (58 11; 93 23) G.B.
Munroe Lake (59 08; 98 30) G.B.

Lota lota

Dominion City (20, 02, 03E) J.K.
Longpine Creek (35, 09, 17E) B.K.
La Salle River (02, 11, 03W) J.K.
Whiteshell River (18, 13, 15E) B.K.
Roaring River (05, 34, 27W) B.K.
Birch River (34, 39, 26W) B.K.
Steeprock River (23, 43, 26W) B.K.
Gods River (54 54; 94 04) B.K.
Weir River (56 56; 93 51) B.K.
Herriot Creek (58 33; 94 22) B.K.

DECAPOD CRUSTACEA OF THE CALANUS EXPEDITIONS IN UNGAVA BAY, 1947 TO 1950[1]

"CALANUS" SERIES NO. 11

H. J. Squires

Abstract

The decapod fauna of Ungava Bay (17 species in 3000 specimens collected) is shown to be similar to that of the shallow water areas of west Greenland. Four species are reported for the first time from Ungava Bay: *Sergestes arcticus* and *Pasiphaea tarda*, ordinarily from deeper and warmer water, and *Eualus macilentus* and *Sabinea septemcarinata*. Species found in or originating in the Pacific were taken in greater numbers. Systematics of each species is treated under occurrence in Ungava Bay, world distribution, and taxonomy. Lengths of most species of shrimp showed that a greater size was reached in females. Maturities with respect to size when first mature, egg size, and times of hatching and spawning are discussed. Males were found to be mature at a size smaller than first-mature females. The high percentage of stations at which decapods, including larvae, were taken, and their occurrence in the stomachs of many seals and fish attest their prevalence and their importance in the area.

Introduction

Previous to the work of the *Calanus* Expeditions, 1947 to 1950, in Ungava Bay, few collections of decapods had been made in this area. A synopsis of the species taken and the names of their collectors is as follows:

Dr. Robert Bell, in 1884, took the following decapods in dredgings at Port Burwell (Smith, 1885 (14)):

4	*Eupagurus krøyeri* Stimpson	
1 F	*Ceraphilus boreas* (Phipps)	= *Sclerocrangon boreas*
2 F	*Hippolyte fabricii* (Krøyer)	= *Eualus fabricii*
1 M, 11 F	*H. phippsii* (Krøyer)	= *Spirontocaris phippsi*
8 M, 7 F	*H. groenlandicus* (J. C. Fabricius)	= *Lebbeus groenlandicus*
5 M, 11 F	*H. polaris* (Sabine)	= *L. polaris*
1 F	*Pandalus montagui* Leach	

A collection by Lucien M. Turner in 1882 to 1885, in Ungava Bay, comprised the following species (Rathbun, 1913 (12)):

Sclerocrangon boreas (Phipps)	
Spirontocaris polaris (Sabine)	= *Lebbeus polaris*
S. fabricii (Krøyer)	= *Eualus fabricii*

In 1884, A. P. Low made dredgings "on the south side of Hudson Strait, between King George Sound and the bottom of Ungava Bay" (Whiteaves, 1901 (20)). Whiteaves, however, reported only *Pandalus montagui* from Hudson Strait as being from Low's collection. No further reference to Low's collection has been seen by the present author.

[1]Manuscript received January 30, 1957.

Contribution from the Fisheries Research Board of Canada, Biological Station, St. John's, Newfoundland. This paper is based on a thesis submitted in partial fulfillment of the requirements for the degree of Master of Science at McGill University, Montreal, Quebec.

The *Diana* Expedition, 1897, collected in Ungava Bay the following species (Rathbun, 1919 (12)):

3 *Eupagurus krøyeri* Stimpson
1 *Hyas coarctatus* Leach

The *Neptune* Expedition, 1903 to 1904, took the following species at Port Burwell (Rathbun, 1919 (12)):

12	*Spirontocaris groenlandicus* (Fabricius)	= *Lebbeus groenlandicus*
1	*S. spina* (Sowerby)	= *S. spinus*
1	*S. lilljeborgi* (Danielssen)	
23	*S. phippsi* (Krøyer)	
6	*S. polaris* (Sabine)	= *Lebbeus polaris*
17	*S. fabricii* (Krøyer)	= *Eualus fabricii*
20	*S. gaimardi* (Milne-Edwards) (varying toward *S. g. belcheri*)	= *E. gaimardi* and *E. g. belcheri*
1	*Sclerocrangon boreas* (Phipps)	
	Nectocrangon lar (Krøyer)	= *Argis dentata* Rathbun

The *Calanus* Expeditions, 1947 to 1950, in Ungava Bay, took 17 species in all, which comprise, in addition to the species collected previously in this area, the following four species:

Sergestes arcticus Krøyer
Pasiphaea tarda Krøyer
Eualus macilentus (Krøyer)
Sabinea septemcarinata (Sabine)

In addition, the *Calanus* Expeditions collected larvae of species mentioned in the families Pandalidae, Hippolytidae (most species), and Crangonidae (except *Sclerocrangon*), as well as larvae of *Eupagurus krøyeri* and *Hyas coarctatus*.

A more recent collection (August 9 to 28, 1954) of decapods from Brunnich's murre food to young on Akpatok Island, Ungava Bay, yielded the following species (Tuck and Squires, 1955 (19)):

7 *Pandalus montagui* Leach
14 *Lebbeus polaris* (Sabine)
1 *L. groenlandicus* (Fabricius)
1 *Spirontocaris spinus* (Sowerby)
55 *Argis dentata* Rathbun

Areas adjacent to Ungava Bay have been collected in very extensively to the east (Davis Strait, Baffin Bay, and particularly west Greenland) but less extensively to the west (Hudson Bay). Some species collected in Hudson Bay and Strait to which Whiteaves (1901 (20)) refers are:

Pandalus montagui
Spirontocaris phippsi
Sclerocrangon boreas

Hyas coarctatus was mentioned by Rathbun (1925 (12)) as collected by Preble in 1900.

The *Neptune* Expedition also collected in Hudson Bay the following species (Rathbun, 1919 (12)):

Lebbeus groenlandicus
L. polaris
Eualus fabricii
E. gaimardi

West Greenland and adjacent areas have been explored very extensively, and decapod species were collected by the *Alert* (British Arctic Expedition, 1875 to 1876), *Ingolf* Expedition (1895 to 1896), the Godthaab Expedition (1928), Treaarexpeditionen til Christian d. X's Land (1931 to 1934), 6th and 7th Thule Expeditions (1933), and *Dana* Expedition (1933) and were taken in many other smaller collections, all of which are reviewed by Hansen (1908 (8)), Stephensen (1935 (15)), and Heegard (1941 (9)). Species collected from west Greenland, Davis Strait, and Baffin Bay may be separated according to whether they were taken in shallow or deep water, as follows:

Shallow water species	Depths, meters	Shallow water species	Depths, meters
Pandalus montagui	64	*E. macilentus*	16–100
Lebbeus microceros	—	*Sabinea septemcarinata*	10–100
L. groenlandicus	0– 50	*Argis dentata*	0–100
L. polaris	4–350	*Sclerocrangon boreas*	0–150
Spirontocaris phippsi	4– 70	*Eupagurus pubescens*	0–200
S. lilljeborgi	12– 16	*Hyas araneus*	60–160
S. spinus	8– 50	*H. coarctatus*	0–150
Eualus fabricii	4– 50	*Chionoecetes opilio*	160
E. gaimardi (incl. *belcheri*)	12–100		
Deep water species		**Deep water species**	
Sergestes arcticus (pelagic)	500–1600	*B. payeri*	450– 820
Gennadas elegans (")	500–2800	*Pontophilus norvegicus*	500– 800
Hymenodora glacialis (")	250–2000	*Sabinea sarsi*	150– 200
Parapasiphaë sulcatifrons (")	1000–2700	*S. hystrix*	750–1100
Pasiphaea tarda (")	800–1200	*Sclerocrangon ferox*	450– 880
Ephyrina benedicti (")	300–3500	*Polycheles nanus*	1600
Acanthephyra multispina (")	300–3000	*Munidopsis antoni*	2400
Pandalus propinquus	600–1400	*M. curvirostra*	650– 750
P. borealis	150– 700	*Munida tenuimana*	500–1200
Bythocaris gracilis	700	*Lithodes maja*	140– 550
B. leucopis	140– 500	*Neolithodes grimaldi*	1000

It may be seen that almost all the shallow water species from west Greenland were also taken in Ungava Bay (except *L. microceros*, *Eupagurus pubescens* (Hansen, 1908 (8), believes this to be synonymous with *E. krøyeri*), *Hyas araneus*, and *Chionoecetes opilio*). However, the pelagic deep-water species *Pasiphaea tarda* and *Sergestes arcticus* were taken in shallower waters than reported heretofore, near the entrance to Ungava Bay by the *Calanus* Expeditions, 1947 to 1950.

Key to Species

The following artificial key to species collected, and allied species which occur in areas adjacent to Ungava Bay, has been compiled from several sources (chiefly, Sund, 1912 (16); Schmitt, 1921 (13); Rathbun, 1929 (12);

Holthuis, 1947 (10), 1955 (10)). The numbers of epipods on periopods, or the presence of exopods on the third maxilliped in some species have been included, because separation of species is often not otherwise possible in damaged specimens from stomach contents of fish and seals.

1.*a* Body laterally compressed. Pleopods used for swimming.....Suborder NATANTIA—2

2*a*. First three pairs of periopods chelate; pleura of second segment of abdomen not overlapping those of the first or third segments. Gills dendrobranchiate.....Tribe PENAEIDEA—3

3*a*. Last two pairs of legs as well developed as the first three pairs..Family Penaeidae

3*b*. Last one or two pairs of legs not as large as the first three pairs, rudimentary or wanting.....Family Sergestidae

a. Rostrum very short. One antennular flagellum very long, the other very short. First joint of antennular peduncle much longer than the third..*Sergestes arcticus*

2*b*. First two pairs of periopods chelate; pleura of second segment of abdomen overlapping those of the first and third segments. Gills phyllobranchiate...Tribe CARIDEA—4

4*a*. Exopods on all periopods. Cutting edge of chela pectinate.....Family Pasiphaeidae—5

5*a*. Basis of second periopod with 7 to 12 spines.....*Pasiphaea multidentata*

5*b*. Basis of second periopod with one to four spines.....*Pasiphaea tarda*

4*b*. No exopods on periopods..... 6

6*a*. First periopods chelate..... 7

7*a*. Rostrum laterally compressed, long, armed above with spines, moveable for the most part, and armed with fixed teeth below. First two pairs of periopods greatly unequal, carpus of second pair annulated. Mandible with palp.....Family Pandalidae—8

8*a*. Third abdominal segment somewhat carinated dorsally and armed with a short spine or lobe. Carpus of right second periopod with about 25 annulations.....*Pandalus borealis*

8*b*. Third abdominal segment without carina or lobe or spine..... 9

9*a*. Carpus of right second periopod with about five annulations.....*Pandalus propinquus*

9*b*. Carpus of right second periopod with about 20 annulations.....*Pandalus montagui*

7*b*. Rostrum toothed; no moveable spines, usually well developed, sometimes reduced. Right and left periopods equal, first pair stouter and usually shorter than the second; carpus of second pair of periopods with seven annulations.....Family Hippolytidae—10

10*a*. Supraorbital spines present on carapace.....11

11*a*. Carapace with two supraorbital spines at each side. Third maxilliped with an exopod.....*Spirontocaris*—12

12*a*. Rostrum with equal teeth above and below, and extending on to carapace to anterior third....*Spirontocaris phippsi*

12*b*. Rostrum with unequal teeth.....13

13*a*. Teeth of rostrum continued on carapace reaching almost to posterior margin. Rostrum short, ending in an arcuate gap between two spinous tips.....*S. spinus*

13*b*. Teeth dorsally on carapace not nearly reaching posterior margin; rostrum ending in one long point.....*S. lilljeborgi*

11*b*. Carapace with one supraorbital spine on each side. Third maxilliped without an exopod.....*Lebbeus*—14

14*a*. Pleura of abdominal segments armed laterally with spines. Epipod on first three periopods.....*Lebbeus groenlandicus*

14*b*. Pleura of abdomen rounded, unarmed.....15

15*a*. Rostrum as long as antennular peduncle. Epipod on first two periopods.....*L. polaris*

15*b*. Rostrum not exceeding first segment of antennular peduncle. Epipod on first three periopods.....*L. microceros*

10*b*. Carapace with no supraorbital spines. Third maxilliped with an exopod.....*Eualus* –16

16*a*. Rostrum about as long as rest of carapace.....17

17*a*. Terminal half of rostrum without spines above. Epipod on first periopod only.....*Eualus fabricii*

17*b*. Terminal half of rostrum with spines above. Epipods on first two periopods.....18

18*a*. Tubercle dorsally on third abdominal segment, mostly with a strong hook.....*E. gaimardi belcheri*

18*b*. No tubercle dorsally on the third abdominal segment.....*E. gaimardi*

16*b*. Rostrum shorter than rest of carapace.....*E. macilentus*

6*b*. First periopods subchelate. Rostrum when present generally small, usually dorsally flattened.....Family Crangonidae—19

19*a*. Second pair of periopods chelate.....20

20*a*. Dactyls of fourth and fifth periopods not dilated, not natatorial. Carapace with strong sculpture.....*Sclerocrangon*—21

21*a*. Rostrum short, horizontal above, an axe-shaped expansion forming its keel.....*S. boreas*

21*b*. Rostrum longer with tip ascending, expansion below also pointed anteriorly, obliquely downward.....*S. ferox*

20*b*. Dactyls of fourth and fifth periopods dilated, natatorial.....*Argis* –22

22*a*. Carinae on sixth abdominal segment each forming a tooth directed posteriorly.....*A. dentata*

22*b*. Carinae on sixth abdominal segment rounded posteriorly, each not forming a tooth.....*A. lar*

19*b*. Second pair of periopods not chelate, smaller than the first, rudimentary.....*Sabinea*—23

23*a*. Rostrum obtuse.....*S. septemcarinata*

23*b*. Rostrum acute.....*S. sarsi*

1*b*. Body generally depressed. Abdominal appendages reduced, sometimes absent, not used for swimming.....Suborder REPTANTIA—24

24*a*. Carapace not fused with epistome. Abdomen anomurous, showing some traces of function other than that of reproduction; asymmetrical, biramous limbs on sixth segment.....Tribe ANOMURA

Uropods present, modified for holding in hollow objects; abdomen soft, showing no trace of segmentation. Hermit crabs.....Family Eupaguridae—25

25*a*. Left hand with outer margin inflexed, a well-defined ridge in middle with one principal row of spines; larger face concave.....*Eupagurus krøyeri*

25*b*. Left hand with outer margin arcuate, not strongly ridged, a double row of spines on crest at middle; larger face convex.....*Eupagurus pubescens*

24*b*. Carapace fused with epistome, at least at sides. Abdomen brachyurous, small, straight, symmetrical, bent under thorax, and without biramous limbs on sixth segment.....Tribe BRACHYURA

Fore part of body narrow, forming a distinct rostrum.....Family Majidae—26.

26*a*. Carapace about as long as broad. Basal article of antenna long and narrow.....*Chionoecetes opilio*

26*b*. Carapace much longer than broad; rostrum elongate.....*Hyas*—27

27*a*. Carapace subtriangular; basal article of antenna triangular, pointed anteriorly, smooth.....*Hyas araneus*

27*b*. Carapace lyrate; basal article of antenna almost rhomboidal, narrowing anteriorly, knobbed.....*Hyas coarctatus*—28

28*a*. Carapace to rostrum length, 4.5 to 6.4 : 1.....Forma *typica*

28*b*. Carapace to rostrum length, 7.1 to 9.3 : 1.....Forma *alutaceus*

Methods

Adults examined for this paper were taken by dredge (steel mesh in 1947, 1948, and 1949; and with rope bag in 1950, which was used in an open meshless frame and enclosed in the wire-meshed dredge in most sets), beam-trawl (a few sets only), stramin net which touched bottom, fine-meshed nets Nos. 5, 00, and 6 which touched bottom inadvertently in plankton towing, No. 00 towing in current at 40 meters (bottom depth 185 meters), and shrimp net on bottom. A considerable number of specimens were taken also from stomach contents of cod (*Gadus callarias* Linné), sculpin (? *Myoxocephalus groenlandicus* Cuvier & Valenciennes), bearded seal (*Erignathus barbatus* (Erxleben)), ringed seal (*Phoca hispida* Schreber), harbor seal (*Phoca vitulina* Linné), and harp seal (*Phoca groenlandica* Erxleben). A few specimens of *Hyas* sp. were taken also by hand on the shore.

Specimens, eggs, etc., were measured as preserved in about 7% formalin. Carapace lengths were measured from the posterior margin of the carapace to the posterior margin of the orbit (Chace, 1940 (1)), and total lengths from the tip of the rostrum to the tip of the telson, all with vernier calipers: the calipers were adjusted to the length of carapace under low power of a dissecting microscope in very small specimens (carapace lengths 3 to 4 mm.). Only animals in good condition were measured; many from stomach contents could not be measured. The greater diameter of an egg was measured directly at a magnification of 10×, estimated to the nearest tenth of a millimeter on a Turtox millimeter grid which had each printed line center scored with a sharp-pointed scalpel. Nonovigerous and ovigerous females were slit open and a few eggs removed from the ovary for measuring; largest eggs from the ovary and pleopods were used for the egg measurements recorded for each specimen.

Sex was determined from examination for appendix masculina in shrimp or prawns and spider crabs, appendages and position of sexual ducts in hermit crabs, and petasma in *Sergestes* sp. Sizes of appendices masculinae and eggs, or presence of eggs on pleopods, were used for a gross determination of maturity.

The number of each station referred to in the systematic account is given in the station lists of the *Calanus* Expeditions, 1947 to 1950 (Dunbar and Grainger, 1952 (4); Grainger, 1954 (7)). Numbers of specimens and of each sex are given following the station number—the number of specimens in parentheses when not the same as the number sexed. The definition of "arctic", "subarctic", and "boreal" follows that given by Dunbar (1953 (3)).

Synopsis of the Species

The following species were taken in Ungava Bay. World distribution and some variations in taxonomy of the specimens examined is indicated.

Family SERGESTIDAE

1. *Sergestes arcticus* Krøyer, 1885. Sund, Oscar, 1920; p. 8, Fig. 5; Hansen, H. J., 1908, p. 82

In all, 267 specimens were taken. Of these, 88 were taken by shrimp net and the rest from stomach contents, as follows: cod, 174; harp seal, 4; and ringed seal, 1. Seventy-one males and 80 females examined and measured were all adult and ranged from 9 to 16 mm. in carapace length. Depths where cod were taken were 15 to 37 meters, and the shrimp net fished at 27 to 37 meters. No larvae of *Sergestes* were taken in plankton net tows.

Occurrence at stations:
1947—44: 1M, 1F; 45: (24) 3M, 17F
1948 -Tunnusaksuk Fjord: (1); 74, 77, and 78: (2) 1F; between Bush and Killinek Islands: (4)
1949—105: 13M, 13F
1950 - Resolution Island, AS28: (110) 47M, 38F; AS28: (88) 17M, 23F; AS28: (10) 3M, 4F

Bathypelagic in subarctic and boreal waters in the Atlantic only. East and west Greenland to Nova Scotia and mid-Atlantic; coast of Norway, 65° 20′ N., and south to the western part of the Mediterranean; a few were taken to the south of Australia by the *Challenger* (Heegard, 1941 (9, p. 61, map Fig. 27)). The *Calanus* Expeditions extend the range of this species westward to Hudson Strait (Resolution Island) and to Port Burwell and Tunnusaksuk Fjord in Ungava Bay, in shallower water than reported heretofore.

Family PASIPHAEIDAE

2. *Pasiphaea tarda* Krøyer, 1854. Sund, Oscar, 1912

The only way of collecting this species by the *Calanus* Expeditions was from stomach contents of Atlantic cod (*Gadus callarias* L.), and 46 specimens in all were collected. Six males and 17 females examined were adult, ranging in carapace lengths from 18 to 44 mm. No larvae of this species were taken. Cod were taken in depths of 15 to 79 meters.

Occurrence at stations:
1947—44: (1)
1949—105: (36) 3M, 14F
1950—AS28: 3M, 3F

A north Atlantic bathypelagic species in the subarctic and boreal areas, never in the Arctic; northern Europe to Ireland; Iceland; southeast and west coasts of Greenland and Davis Strait (J. G. De Man, 1920 (2)). Heegard (1941 (9)) gives as a record of distribution the east coast of North America at Massachusetts, but this must be from Smith (1879 (14)), who considered *P. multidentata* to be synonymous with *P. tarda*. *P. multidentata*, however, is described as a distinct species by most authors; it has been taken occasionally off Newfoundland as has *P. tarda* also, from deep water (H. J. Squires, unpublished). The *Calanus* Expeditions extend the distribution of *P. tarda* to the northeast coast of America at Resolution Island and Port Burwell, and in shallower water than reported heretofore.

Family PANDALIDAE

3. *Pandalus montagui* Leach, 1814. Rathbun, M. J., 1929, p. 8, Fig. 5

Eighty-one specimens were taken throughout the area: 3 by stramin net which touched bottom, 11 by dredge and beam-trawl; and 37 from cod, 29 from ringed seal, and 1 from bearded seal stomach contents. In good condition when examined were 23 males, 10 to 18 mm., and 17 females, 20 to 25 mm. in carapace length. Depths, 15 to 275 meters. Temperatures, −1.39 to −1.00° C. Salinities, 31.87 to 33.53‰.

Occurrence at stations:
1947—18: 1M, 1F; 45: 4M; 45: (17) 4M, 10F
1948—Burwell Hr.: (4); 103: 3M, 2F; 105: (17) 7M, 7F; 107: 2M
1950—Cape Hopes Advance: (26) 1M; 208: 1M; 224: (1); 224: (2) 1F

Subarctic and boreal (Stephensen, 1935 (15)); part of the endemic archibenthal fauna of the North Atlantic (Ekman, 1953 (5)). White Sea, Murman Sea; from the extreme north of Norway to the English Channel: the whole of the North Sea, Skagerrak, Kattegat, and most western part of the Baltic, Rockall; around the coasts of Iceland; Baffin Bay; east coast of North America as far south as latitude 41° 25′ N. Depths 15 to 290 meters. (De Man, 1920 (2).)

Spines on the rostrum $\frac{6 - 17}{4 - 6}$, two to seven of which are on the carapace in these specimens; given for other areas $\frac{12 - 16}{6 - 9}$, three to four of which are on the carapace (Rathbun, 1929 (12)). Four to six pairs of spines laterally on the telson, sometimes not paired.

Family HIPPOLYTIDAE

4. *Spirontocaris lilljeborgi* (Danielssen, 1859). Rathbun, 1929, p. 14, Fig. 13; Holthuis, 1947, p. 8

Only two specimens of this species were taken—in the stomach contents of bearded seals. One male was adult at 7 mm. carapace length.

Occurrence at stations:
1948—15 miles ENE. of the Gyrfalcon Islands: 1M
1949—25 miles off Payne Bay: (1)

Subarctic and boreal; Europe, from the Murman Sea south to the Kattegat; in Davis Strait and North America from Nova Scotia to 37° N. (Heegard, 1941 (9)); north coast of Alaska (Rathbun, 1904 (12)). The collections of the *Calanus* Expeditions extend the range of this species to Ungava Bay.

Hansen (1908 (8, p. 60)) states that this species is boreal and not arctic, but refers to Rathbun's record on the north coast of Alaska at 19 fathoms (Rathbun, 1904 (12, p. 68)). Stephensen (1935 (15, p. 83)) calls this species boreal and accidental in low-arctic waters. Heegard (1941 (9)) also ignores the Alaska record, calling it boreal. Ekman (1953 (5, p. 153)) gives this species as an example of boreal submergence.

5. *Spirontocaris phippsi* (Krøyer, 1841). Holthuis, 1947, p. 8; Rathbun, 1929, p. 13, Fig. 12

S. turgida. Hansen, 1908; Heegard, 1941; Ekman, 1953

In all, 137 specimens were taken: 21 by stramin net which touched bottom; 24 by dredge; and 18 in cod, 32 in ringed seal, 36 in bearded seal, and 6 in harbor seal stomach contents. Depths, where taken by dredge, were 14 to 110 meters. Temperatures, −1.39 to 2.07° C. Salinities, 29.40 to 33.42‰.

Occurrence at stations:

1947—13: (11) 1M, 6F; 18: (10) 3M, 6F; 33: 2M, 2F; 45: 3F; 45: (6) 1M, 4F; 48: 1F

1948 –Koksoak River mouth: (34) 1M, 32F; 15 miles ENE. Gyrfalcon Islands: (2) 1F; 58: 2F; 59: 4F; off Whale River: (28) 11F

1949—105: (9) 1M, 7F; Button Islands: (6) 1F; 126: 2F

1950 Cape Hopes Advance: (1); 202: (3) 2F; 208: 1M; 210: 5F; 222: 3F; 224: 2F

Circumpolar, in subarctic waters; southward to northern Norway; Cape Cod (east coast of North America) and Plover Bay (Siberian east coast). Depths 11 to 225 meters. (Holthuis, 1947 (10).)

Spines on rostrum $\frac{4 - 18}{3 - 8}$, zero to six of which are on the carapace (somewhat less in males than females) in these specimens; $\frac{7 - 12}{4 - 7}$, four to five of which are on the carapace, has been given for other areas (Rathbun, 1929 (12)). Two to seven pairs of spines laterally on the telson, often not paired completely.

6. *Spirontocaris spinus* (Sowerby, 1805). Holthuis, 1947, p. 8

S. spina. Rathbun, 1929, p. 14, Fig. 14

In all, 185 specimens were taken: 77 by dredge and beam-trawl; 34 by stramin net which touched bottom; and, in stomach contents, 47 in cod and 21 in bearded seal, 3 in ringed seal, and 3 in harbor seals. Depths, where taken by dredge, were 9 to 275 meters. Temperatures, −1.39 to 3.10° C. Salinities, 29.40 to 33.42‰.

Occurrence at stations:

1947—3: 1F; 11: 1F; 13: 3M, 5F; 18: (8) 2M, 4F; 33: 4M, 3F; 44: (2); 45: (9) 4M, 4F; 48: 1M, 1F

1948 Off Koksoak River: (1); 15 miles ENE. Gyrfalcon Islands: (3) 2F; 59: 2F

1949 103: 3M, 16F; 106: 1F; 107: 2M, 2F; Port Burwell: (1); 105: (1); 105: (22) 4M, 9F; Button Islands: (3); off Payne Bay: (1); 126: (1); 128: 11M, 7F

1950 Cape Hopes Advance: (5); 201C: 1F; 202: (12) 2M; 203: 2F; 208: 2M, 5F; 210: 2M, 3F; 222: 9M, 15F; 224: 2F; 226: 1M, 1F; 224: (10) 2M, 5F

Circumpolar, subarctic, and boreal; southward to the northern North Sea; Iceland; Greenland; North America, Massachusetts Bay to the Behring Sea, Alaska Peninsula; Siberian east coast. Depths 16 to 400 meters (Heegard, 1941 (9); Holthuis, 1947 (10)). This species is also denoted as a constituent of the archibenthal fauna (Ekman, 1953 (5)).

Major spines on rostrum $\frac{8 - 28}{1 - 5}$, 4 to 21 of which are on the carapace in these specimens; given for other areas $\frac{9 - 33}{2 - 5}$, with an average of 18 to 19 above (Rathbun, 1929 (12)). The spines counted above on the rostrum and carapace are major ones only; there are very many secondary, serrulate spines in addition. Four to 10 spines laterally on the telson, often not always paired.

7. *Lebbeus groenlandicus* (J. C. Fabricius, 1775). Holthuis, 1947, p. 9
Spirontocaris groenlandica. Rathbun, 1929, p. 11, Fig. 8

In all, 413 specimens were taken: 159 by dredge and beam-trawl; 7 by stramin net which touched bottom; 2 by shrimp net on the bottom; and 40 in cod, 176 in bearded seal, 14 in ringed seal, and 14 in harbor seal stomach contents. Depths, where dredged, etc., 18 to 275 meters. Temperatures, −1.39 to 2.16° C. Salinities, 28.99 to 33.53‰.

Occurrence at stations:

1947—3: 2M, 2F; 11: (7) 2M, 3F; 13: 1M, 1F; 18: (1); 20 and 21: 3F; 28: 6M, 8F; 30: 20M, 13F; 33: 2M, 6F; 45: (11) 1M, 7F; 48: 3M, 1F

1948—30 miles toward Burwell from George River: (2); Koksoak River mouth: (12) 3F; 53: 1M; 15 miles ENE. Gyrfalcon Islands: (39) 8M, 4F; 58: 6M, 1F; 59: 4M, 5F; off Whale River: (45) 4F

1949—103: 10M, 16F; 106: 3F; 105: (14) 3M, 7F; Button Islands: (15) 6F; off Payne Bay: (5); 126: 3M, 3F; 103: 1M, 3F

1950—Cape Hopes Advance: (3); 202: (69) 2M, 10F; 205: (2); 206: 2M; 208: 1M, 2F; 210: 3M, 8F; 212: (4); 216: 1F; 222: 5M, 3F; 224: (13) 3M, 3F; 226: 4M, 6F; 236: (9) 1F; AS28: (3) 1M, 1F

Arctic, subarctic, and boreal; Pacific (Heegard, 1941 (9)). East and west Greenland, southward to Massachusetts Bay; arctic Canada; Behring Sea to Puget Sound; Sea of Okhotsk. Depths 2 to 210 meters (Holthuis, 1947 (10)).

Spines on rostrum $\frac{1 - 4}{1 - 4}$, plus four spines invariably on the carapace in these specimens; $\frac{2 - 3}{2 - 3}$, plus four spines invariably on the carapace, has been given for other areas (Rathbun, 1929 (12)). Six to seven spines laterally on the telson (Rathbun, 1929 (12)), 4 to 10 laterally on telson in the specimens examined.

8. *Lebbeus polaris* (Sabine, 1821). Holthuis, 1947, p. 9
Spirontocaris polaris. Rathbun, 1929, p. 12, Fig. 9

As in west Greenland (Stephensen, 1935 (15)) this was the most abundant species taken in Ungava Bay by the *Calanus* Expeditions.

In all, 473 specimens were taken: 211 by dredge and beam-trawl; 23 by stramin net which touched bottom; 2 by plankton net No. 00 at 40 meters (not on bottom); 123 by plankton net No. 5 which touched bottom; 19 by shrimp net; and 69 in cod, 13 in ringed seal, 8 in bearded seal, and 5 in harbor seal stomachs. Depths, where taken by dredge, etc., 5 to 275 meters. Temperatures observed, −1.39 to 3.40° C. Salinities, 29.40 to 33.53‰.

Occurrence at stations:

1947—3: 4F; 7: 3M, 4F; 11: 3M; 18: (5) 4F; 20 and 21: 2M, 2F; 28: 2F; 33: 1M; 45: (37) 12M, 22F

1948—30 miles toward Port Burwell from George River: (1); Koksoak River mouth: (7); 15 miles ENE. Gyrfalcon Islands: (3); 58: 5F; 59: 14M, 29F; off Whale River: (1)

1949—103: 25M, 36F; 106: 1M, 1F; 107: 1M, 1F; Port Burwell: (6) 1M; 105: (20) 11M, 8F; Button Islands: (5); 123: (123) 3Juv, 8M, 11F; 124: 10Juv, 1M, 1F; 126: 1F; 128: (2); 103: 3M, 2F

1950—Cape Hopes Advance: (3); 206: 1F; 208: (15) 4M, 10F; 210: 6M, 11F; 216: 3F; 222: (29) 11M, 17F; 224: (18) 2M, 8F; 226: 2M, 1F; Resolution Island: 4M, 17F

Arctic, subarctic, and boreal; circumpolar. Southward to the Skaggerak and Hebrides, and to Cape Cod in North America; Behring and Okhotsk Seas and the Aleutian Islands. Depths 0 to 930 meters (Holthuis, 1947 (10)).

Spines on rostrum $\frac{0-6}{0-6}$, zero to five of which are on the carapace, with 2 to 10 pairs of spines on the telson, laterally, in these specimens; $\frac{0-8}{1-5}$, with seven to nine pairs of spines on the telson, has been given for other areas (Rathbun, 1929 (12)). In males only, the rostrum and carapace are occasionally entirely free of spines and the blade of the rostrum is reduced and thickened dorsally. This appears to be a condition present in mature animals only. It has been referred to as a variation with a reduced rostrum (Rathbun, 1929 (12)).

9. *Eualus fabricii* (Krøyer, 1841). Holthuis, 1947, p. 10
Spirontocaris fabricii. Rathbun, 1929, p. 15, Fig. 15

In all, 416 specimens were taken: 173 by dredge and beam-trawl; 44 in stramin net which touched bottom; 39 by No. 00 plankton net which touched bottom; 6 by shrimp net; and 70 in cod, 27 in bearded seal, 37 in ringed seal, and 20 in harbor seal stomachs. Depths, where taken by dredge, etc., 10 to 275 meters. Temperatures, −1.39 to 3.40° C. Salinities, 28.49 to 33.53‰.

Occurrence at stations:

1947—7: 3M, 13F; 11: 4M, 9F; 13: 1F; 18: 27M, 9F; 20 and 21: 2M, 10F; 27: 1M, 2F; 28: 1M, 3F; 33: 7M, 11F; 44: 1F; 45: 6M, 15F; 45: (28) 6M, 18F

1948—Koksoak River mouth: (37); 53: IF; 15 miles ENE. Gyrfalcon Islands: (7) 2M; 58: 5M, 1F; 59: 15F; off Whale River: (1)

1949—102: (1); Port Burwell Hr.: 1F; 103: 1Juv., 2M; 107: 13F; Mission Cove: (1); Port Burwell: (11) 3F; 105: 1M; Button Islands: (20) 6M; 123: (14) 5Juv, 4F; off Payne Bay: (4) 3F; 124: 1M, 3F; 126: 10F; 128: 17M, 8F; 103: 3F

1950—203: 5M, 2F; 206: 2F; 208: (10) 4M, 5F; 210: 1M, 11F; 222: 1F; 224: 1M, 2F; 226: 5F; 224: (2) 1F; 236: (1); Resolution Island: 3M, 4F

Arctic, subarctic, and boreal. A Pacific species extending to west Greenland (Stephensen, 1935 (15)); from the Siberian east coast and Japanese Sea through arctic Alaska and arctic Canada to west Greenland and southward to Massachusetts Bay on the east coast of the United States. Depths 4 to 200 meters (Holthuis, 1947 (10)).

Spines on rostrum and carapace $\frac{1 - 5}{1 - 5}$, of which zero to one are on the rostrum (mostly none), and two to six pairs of spines laterally on the telson in specimens examined; $\frac{2 - 6}{1 - 5}$, zero to two on the rostrum, four pairs of spines laterally on the telson has been given for other areas (Rathbun, 1929 (12)).

10. *Eualus gaimardi* (H. Milne-Edwards, 1837). Holthuis, 1947, p. 10
Spirontocaris gaimardi. Rathbun, 1929, p. 16, Fig. 16

In all, 102 specimens were taken: 34 in dredge and beam-trawl; 1 in stramin net which touched bottom; 4 in No. 6 plankton net which touched bottom; 3 in No. 0 plankton net which touched bottom; 1 in shrimp net; and 33 in cod, 3 in bearded seal, and 23 in ringed seal stomach contents. Depths, 15 to 275 meters. Temperatures, −1.39 to 3.10° C. Salinities, 28.49 to 33.53‰.

Occurrence at stations:

1947—11: 1F; 18: 1F; 20 and 21: 1F; 33: 4Juv, 3F; 45: 3M, 9F; 45: (20) 7M, 11F

1948—15 miles ENE. Gyrfalcon Islands: (1); 59: 2F

1949—Port Burwell Hr.: (2); 103: 2F; Port Burwell: (20) 2F; 105: (10) 2M, 7F

1950—Cape Hopes Advance: (2); 201C: 1M; 202: (1); 224: 1M, 1F; 234: (3) 1M, 1F; Resolution Island: (2) 1F

Arctic, subarctic, and boreal; a boreo-arctic or pan-arctic species, circumpolar (Heegard, 1941 (9)). Southward to the North Sea, Yarmouth, and Kiel; east coast of North America to Cape Cod; west coast of North America

to Sitka; shrimp taken in greatest numbers at Point Barrow, Alaska (MacGinitie, 1955 (11)); Siberia. Depths, 10 to 900 meters (Holthuis, 1947 (10)).

Spines on rostrum $\frac{6 - 11}{2 - 5}$, two to three on carapace, and two to six pairs of spines laterally on the telson in these specimens; $\frac{5 - 10}{2 - 7}$, three to five on carapace has been given for other areas (Rathbun, 1929 (12)). These specimens were entirely without a lobe or hook on the third abdominal segment, dorsally, similar in males and females. This is thought by some to be characteristic of more southerly areas (Holthuis, 1947 (10)). However, there was a blunt lobe or tubercle on a few others which might be considered to be intermediate between the typical species and its form, *E. gaimardi belcheri*; these were included in the following group assigned to *E. gaimardi belcheri*, which had a strong hook on the lobe. In view of the occurrence together of the typical species and its form, the extremes may not be said to follow a geographical incidence or cline in these areas. Also, as far southerly as St. Mary's Bay, Newfoundland, a considerable number have been taken with a well-developed hook and lobe in all males and females (H. J. Squires, unpublished).

11. *Eualus gaimardi belcheri* (Bell, 1855). Holthuis, 1947, p. 10
Spirontocaris gaimardi belcheri. Rathbun, 1929, p. 16, Fig. 17

In all, 46 specimens were taken: 23 in dredge and beam-trawl; 6 in stramin net which touched bottom; and 7 in cod, 6 in bearded seal, 3 in ringed seal, and 1 in harbor seal stomach contents. Depths, where dredged, etc., 15 to 275 meters. Temperatures, −0.46° C. Salinities, 33.53‰.

Occurrence at stations:
1947—33: 1F; 45: 7M, 4F
1948—15 miles ENE. Gyrfalcon Islands: (1); Keglo Bay: (1)
1949—102: 2F; 103: 6M, 15F; 105: 1F; 103: 4M, 2F
1950—Cape Hopes Advance: (7); 227: (1).

Arctic, subarctic, and boreal; boreo-panarctic; circumpolar (Heegard, 1941 (9)). Southward to the North Sea, and on the east coast of North America to Cape Cod, also on the west coast at Sitka; Point Barrow, Alaska (MacGinitie, 1955 (11)); Siberia. The distribution of this form follows closely that of the typical *E. gaimardi* (Heegard, 1941 (9)).

Spines on the rostrum $\frac{5 - 8}{3 - 5}$, three to four on carapace, and four to six pairs of spines laterally on the telson—not always paired—in these specimens; $\frac{8 - 12}{3 - 5}$, two to four on the carapace, has been given for other areas (Rathbun, 1929 (12)). All these specimens had a lobe or tubercle mostly produced as a hook on the third abdominal segment in males and females.

12. *Eualus macilentus* (Krøyer, 1841). Holthuis, 1947, p. 11
Spirontocaris macilenta. Rathbun, 1929, p. 16, Fig. 18

Only four specimens were taken: one by dredge and three in stomach contents of ringed seal. Depths of dredging, 55 to 73 meters.

Occurrence at stations:
1949—Port Burwell Hr.: 1F; 107: 1F; Port Burwell: (1)
1950—Cape Hopes Advance: (1)

Arctic and subarctic. A Pacific species to west Greenland (Stephensen, 1935 (15)), south to Nova Scotia. Alaska, Okhotsk Sea, Behring Sea and Strait to the Siberian Polar Sea. Depths 150 to 540 meters (Holthuis, 1947 (10)).

Spines on rostrum $\frac{14 - 16}{2 - 3}$, one to three on the carapace and three pairs of spines laterally on the telson in two females examined; $\frac{9 - 16}{1 - 4}$, zero to three spines on carapace and with three pairs of spines laterally on the telson, has been given for other areas (Rathbun, 1929 (12)).

Family CRANGONIDAE

13. *Argis dentata* Rathbun, 1902. Rathbun, 1929, p. 21, Fig. 27
Nectocrangon lar Owen, 1839 (in part). Stephensen, 1935, p. 13
Not *N. lar* (Owen), Rathbun, 1904, p. 137, Fig. 74

Specimens taken number 340; 67 by dredge and beam-trawl; and 7 in cod, 253 in bearded seal, 6 in ringed seal, and 7 in harbor seal stomach contents. Depths, where taken by dredge and beam-trawl, were 18 to 130 meters. Temperatures, where taken, were −1.22 to 2.07° C. Salinities, 29.40 to 33.42‰.

Occurrence at stations:
1947—11: 1M, 2F; 20 and 21: 3M, 1F; 33: 1M, 1F; 45: 3F; 45: (6) 5F
1948—30 miles toward Burwell from George River: (21); Koksoak River mouth: (50) 4F; 15 miles ENE. Gyrfalcon Islands: (63) 7M, 10F; off Leaf Bay: (3); 74, 77, and 78: 1M; off Whale River: (9) 1F
1949—102: 2M, 22F; 107: 1M, 2F; 105: (3) 2F; Button Islands: (7); off Payne Bay: (1); 126: 1M, 5F
1950—Cape Hopes Advance: (32) 5M, 1F; 201C: 1M; 202: (44) 4M, 8F; 203: 5Juv, 4M, 11F; 212: (2); 222: 1M; 236: (31) 4M, 4F

Arctic, subarctic, and boreal; a Pacific species (Heegard, 1941 (9)). Behring Sea southward to southeast coat of Kamchatka and Plover Bay, Siberia, and Aleutian Islands and the Alaska Peninsula to Sitka; (Canadian Arctic) and the Atlantic coast of North America from Greenland to Nova Scotia (De Man, 1920 (2)). Depths 11 to 176 meters (Rathbun, 1904 (12)).

The rostrum is reduced and there is always a line of three spines dorsally on the carapace. Dr. M. J. Rathbun's named specimens of *Argis dentata* and *A. lar*, including type specimens of *A. dentata*, at the United States

National Museum show that these two species are quite distinct. The dorsal carinae of the sixth abdominal segment of specimens of *A. lar* are rounded posteriorly, but in *A. dentata* these carinae are pointed posteriorly to form a tooth in many and in some are merely pointed but not rounded. The latter condition was present in all specimens collected by the *Calanus* Expeditions in Ungava Bay, 1947 to 1950 (Table I). It is not known whether the European authors (Hansen, 1908 (8); Stephensen, 1935 (15); Heegard, 1941 (9)), who consider *A. dentata* and *A. lar* to be synonymous, examined specimens of *A. lar* from the Pacific. Dr. Rathbun examined specimens from Greenland collected by the Princeton Expedition and called them *A. dentata* (Rathbun, 1904 (12, p. 139)). It is presumed, therefore, that *A. lar* is confined in its distribution to the Pacific, and has not been taken farther east than Point Barrow, Alaska (MacGinitie, 1955 (11)).

TABLE I

CONDITION OF POSTERIOR END OF DORSAL CARINAE ON THE SIXTH ABDOMINAL SEGMENT IN SPECIMENS OF *Argis dentata* COLLECTED IN UNGAVA BAY BY THE *Calanus* EXPEDITIONS, 1947 TO 1950

Males		Females	
Sharp-pointed, forming a tooth	Medium-pointed, not forming a tooth	Sharp-pointed, forming a tooth	Medium-pointed, not forming a tooth
14	5	22	27

14. *Sclerocrangon boreas* (Phipps, 1774). Rathbun, 1929, p. 20, Fig. 25

Specimens taken number 227; 9 by dredge, and 1 in cod, 174 in bearded seal, 39 in ringed seal, and 4 in harbor seal stomach contents. Depths, where taken by dredge, 18 to 91 meters. Temperatures, 1.90 to 2.07° C. Salinities, 29.40 to 31.87‰.

Occurrence at stations:

1947—30: 1M; 33: 2M, 1F; Button Islands: (1)
1948—Koksoak River mouth: (45) 5M, 9F; 15 miles ENE. Gyrfalcon Islands: (3) 1F; off Whale River: (38) 3F
1949—105: 1F; Button Islands: (4) 2F; off Payne Bay: 1F; 126: 1F
1950—Cape Hopes Advance: (8) 1F; 202: (32) 8M, 5F; 203: 1M, 2F; 205: (1); 222: 1F; 236: (83) 20F

Arctic, subarctic, and boreal. Widely distributed in the arctic but not known to be circumpolar; it is found also in boreal areas (Heegard, 1941 (9)). Arctic Siberia near Behring Strait and arctic Alaska (most abundant species of large shrimp taken at Point Barrow (MacGinitie, 1955 (11)); southward via Behring Sea to Kilesnov, and the Straits of Georgia, British Columbia; in the Atlantic from Cape Cod northward to the Canadian Arctic from Baffin Land to Melville Island; west and east Greenland, Iceland, the Norwegian coast north of the Arctic Circle, Spitzbergen, Bear Island, and Novaja Zelmya. Depths 0 to 400 meters (Heegard, 1941 (9)).

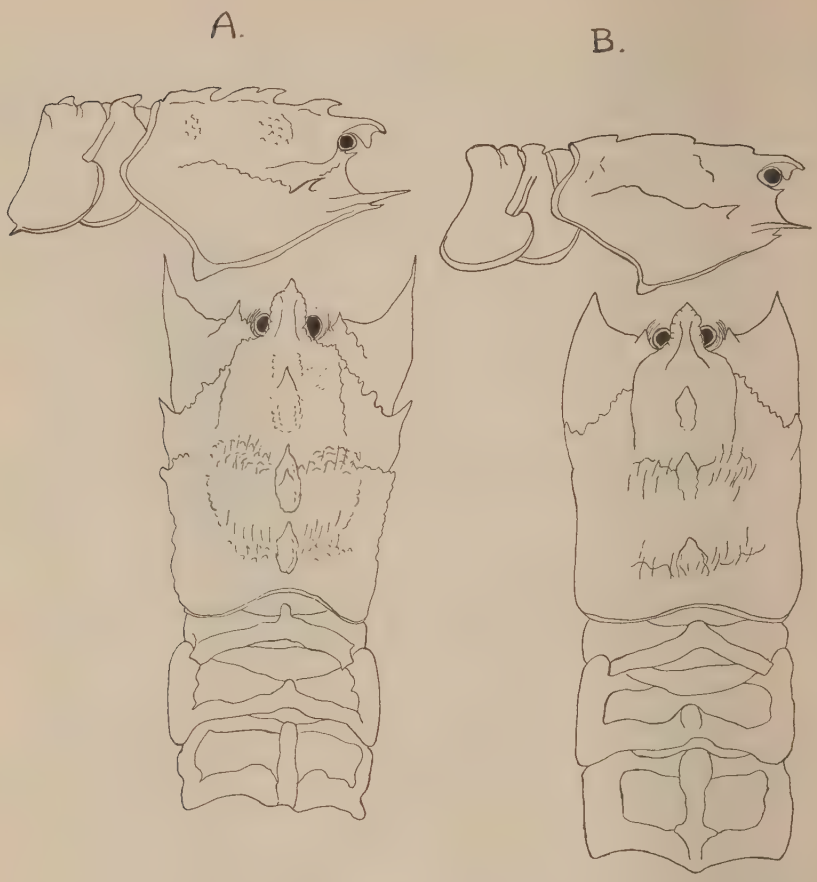

FIG. 1. Diagram of female *Sclerocrangon boreas*, 26 mm. carapace length, typical of Ungava Bay specimens (A); and of female, 25 mm. carapace length, Change Islands, Newfoundland (B).

All specimens had constant characters which differed fairly considerably from those given for the species by Rathbun (1929 (12)), and from specimens like the typical ones described by Rathbun, taken in shallow water in Newfoundland (H. J. Squires, unpublished). However, *Albatross* specimens taken off Newfoundland correspond with the Ungava Bay specimens and intergradations exist in the species material in the United States National Museum which would suggest that these forms are not separate species (Fenner A. Chace, Jr., personal communication). A table of comparison (Table II) and a figure (Fig. 1) show the main differences.

15. *Sabinea septemcarinata* (Sabine, 1824). Rathbun, 1929, p. 22, Fig. 28

Only 12 specimens were taken: 4 by dredge and beam-trawl; and 7 in cod and 1 in bearded seal stomach contents. Depths, where dredged and trawled,

TABLE II

COMPARATIVE CHARACTERS IN A TYPICAL SPECIMEN OF *Sclerocrangon boreas* FROM UNGAVA BAY, COLLECTED BY THE *Calanus* EXPEDITIONS, 1947 TO 1950, AND A SPECIMEN FROM CHANGE ISLANDS, NEWFOUNDLAND, COLLECTED IN 1948, TYPICAL OF THOSE DESCRIBED BY RATHBUN (12), 1929

Female, 26 mm. carapace length, typical of Ungava Bay specimens	Female, 25 mm. carapace length, from Change Islands, Nfld.
Carapacial spines, 3, center one double, high	Carapacial spines, 3, center one single, low
Branchiostegal spines wide-spreading to outside outline of carapace width; long, exceeding rostrum and outer spine on peduncle of antenna	Branchiostegal spines not wide-spreading, included in outline of carapace width; hardly exceeding rostrum and about equal anteriorly to outer spine on peduncle of antenna
Pterygostomian spine reaching further anteriorly than antennal spine	Pterygostomian spine about even with antennal spine
Hepatic spines not included in outline of carapace width	Hepatic spines included in outline of carapace width
Tubercle dorsally on 1st abdominal segment projecting anteriorly higher than carapace edge	Tubercle dorsally on 1st abdominal segment not produced higher than carapace edge
Pleuron of 2nd abdominal segment has a tooth directed posteriorly	No tooth on pleuron of 2nd abdominal segment
Variable number of teeth on pleura of abdominal segments in some specimens	One tooth on each pleuron of abdominal segments

18 to 130 meters. Temperatures, −1.22 to 3.10° C. Salinities, 28.78 to 33.42‰.

Occurrence at stations:
1947—33: 1F; 45: (3) 1M, 1F
1949—102: 1F; 105: (4) 1F
1950—201C: 1F; 202: 1F; 222: 1F

Arctic and subarctic; an arctic circumpolar species (Stephensen, 1935 (15)). Siberian Polar Sea to the Kara Sea, Spitzbergen and Barents Sea, White Sea, Murman Sea, west coast to Norway to the Lofotens and farther south; Iceland; east and west Greenland as far north as Discovery Bay and Grinnell Land; north of Canada (115 to 141° W. long.); south to Massachusetts Bay, east coast of North America. Not known from the Pacific. Depths, 0 to 245 meters (De Man, 1920 (2); Stephensen, 1935 (15)). Taken off Point Barrow, Alaska (MacGinitie, 1955 (11)). The collections of the *Calanus* Expeditions establish its occurrence in Ungava Bay for the first time.

FAMILY EUPAGURIDAE

16. *Eupagurus krøyeri* Stimpson, 1857. Smith, 1879, p. 48; Hansen, 1908, p. 28
Pagurus krøyeri. Rathbun, 1929, p. 27, Fig. 36

Seventy specimens were taken: 60 by dredge and beam-trawl; 1 in stramin net which touched bottom; and 9 in stomach contents of cod. Depths, 15 to 275 meters. Temperatures, −1.18 to 3.10° C. Salinities, 29.76 to 33.53‰.

Occurrence at stations:
1947—11: 1M, 2F; 28: 2F; 33: (17) 8M, 8F; 45: 1M, 2F; 45: (2) 1F
1948—59: 2M; 74, 77, and 78: 1M
1949—103: 2M, 1F; 106: 1Juv, 1M, 4F; 107: 3F; 105: (6); 126: (2) 1M; 103: 1F
1950—201C: 7M, 7F; 203: 1M; 226: 2M, 1F; 231: 1F

Arctic, subarctic, and boreal. An Atlantic species, low-arctic, boreal, more arctic than *E. pubescens* (Smith, 1879 (14)). Greenland to Stellwagen's Bank, east coast of North America, in deeper water to the south; northern Canada; northern Europe. Depths, 5 to 550 meters (Smith, 1879 (14); Rathbun, 1929 (12)).

All the specimens examined were invariably similar to the type. Hansen (1908 (8)) believed this species to be synonymous with *E. pubescens* because he stated that he had found intergrading specimens. Both species occur without intergradations as far as observed in the Newfoundland area (H. J. Squires, unpublished).

Family MAJIDAE

17. *Hyas coarctatus* Leach, 1815. Rathbun, 1929, p. 37, Fig. 51

Seventy-eight specimens were taken: 37 by dredge and beam-trawl; and 10 in cod, 1 in ringed seal, 20 in bearded seal, 4 in harbor seal, and 3 in sculpin stomachs; and 3 by hand on the shore. Depths, 0 to 130 meters. Temperatures, −1.39 to −1.22° C. Salinity, 33.42‰.

Occurrence at stations:
1947—20 and 21: (1); 28: 1M; 45: 1M, 1F; 45: 3F
1948—Leaf Bay: 1M; 74, 77, and 78: 1M; 70: 1M; Port Burwell: 3F
1949—102: 1M; 107: 1F; 105: 2M, 1F; Button Islands: (4); off Payne Bay: (4); 126: 7M, 11F
1950—Cape Hopes Advance: (2); 202: (7); 204: (1); 206: 1M; 208: 2M, 1F; 210: 2M, 2F; 212: (3); 215: (1); 216: (2) 1F; 224: 1F; 226: 2F; 224: (2) 1F

Arctic, subarctic, and boreal. The typical form is boreo-lower arctic (Heegard, 1941 (9)). Atlantic: west Greenland, Hudson Bay, east coast of North America to North Carolina; Iceland up to 66½° N. lat.; northern Europe to 79½° N. lat., southward to the English Channel. Arctic: Mackenzie River, Alaska, Siberian coast to Bennett Island. Pacific: Behring Sea to west coast of Alaska and to Korea. Depths, 3 to 900 fathoms (Heegard, 1941 (9)). *H. coarctatus alutaceus* has been recorded in the Pacific, Arctic, and West Atlantic (Rathbun, 1929 (12)), but this form was not present in the *Calanus* Expeditions collections.

The ratio of carapace length to rostrum length has been used to separate the typical *H. coarctatus* from the form *H. coarctatus alutaceus*. In *H. coarctatus alutaceus* the carapace length is 7.1 to 9.3 times as long as the rostrum length,

TABLE III

RATIO OF CARAPACE LENGTH TO ROSTRUM LENGTH IN *Hyas coarctatus* COLLECTED IN UNGAVA BAY BY THE *Calanus* EXPEDITIONS, 1947 TO 1950

Av. carapace length, mm.	Carapace × rostrum	No. specimens examined
7	2.3	2
12	4.0	1
17	3.4	2
22	4.4	1
27	4.5	8
32	4.6	4
37	5.3	6
42	5.3	7
47	6.0	3
52	6.5	1
57	—	—
62	6.2	1
67	—	—
72	—	—
77	—	—
82	—	—
87	7.3	1

while this ratio is 4.5 to 6.4 times in the typical *H. coarctatus*, carapace lengths 30 to 52 mm. (Rathbun, 1929 (12)). The latter ratios are similar to those found for specimens collected in the Ungava Bay area (Table III).

Lengths and Maturities of Species

Lengths

Each specimen was measured when possible in order to give sizes of the animals which would allow comparisons with those of specimens from other areas (a basis of comparison is the length of each species when first mature; Chace, 1940 (1)). A regional comparison is not attempted in this paper. Since whole lengths, however, are given by many authors, while carapace lengths are used in this paper, regression equations are given for conversion of carapace lengths to whole lengths. These equations were calculated from sight curves drawn to points plotted from average whole lengths at each carapace length (Figs. 2 to 4). The curves in Figs. 2 to 4 were weighted according to the number of measurements supporting each average; measurements of males and females were combined for these curves.

It is striking that in the shrimp species collected, all, with the possible exception of *Pasiphaea tarda*, had females which exceeded the males in length (Figs. 2 to 4). This was particularly evident in species taken in large quantity such as *Lebbeus polaris*, *Eualus fabricii* (Fig. 3), and *Lebbeus groenlandicus* (Fig. 2). It was less evident in *Eualus gaimardi belcheri* (Fig. 4). In hermit crabs (*Eupagurus krøyeri*) and spider crabs (*Hyas coarctatus*) the males generally exceeded the females in length (Fig. 4), although average lengths were not greatly different. The array of lengths in female shrimp, also, shows considerably greater scatter than in males and possibly a greater growth rate in females. The generally smaller size of males compared with females in

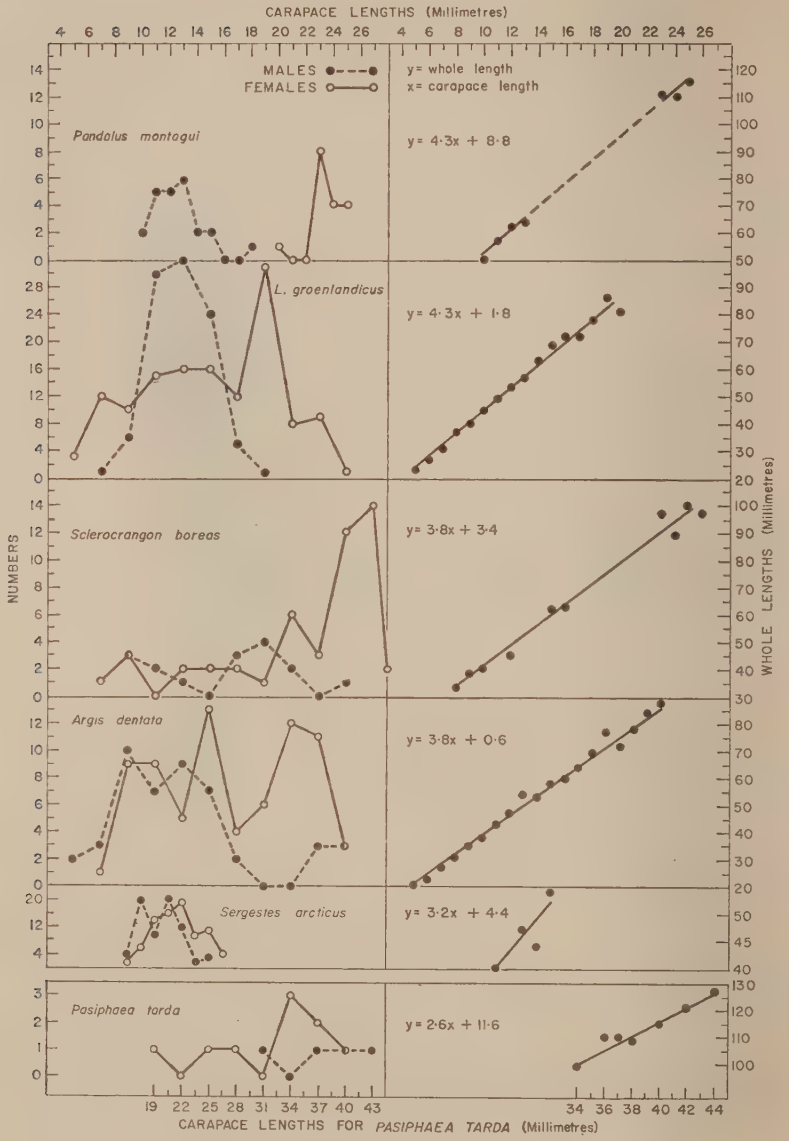

FIG. 2. Carapace length frequencies and regression curves for conversion of carapace lengths to whole lengths in *Pandalus montagui*, *Lebbeus groenlandicus*, *Sclerocrangon boreas*, *Argis dentata*, *Sergestes arcticus*, and *Pasiphaea tarda*. *Calanus* Expeditions in Ungava Bay, 1947 to 1950.

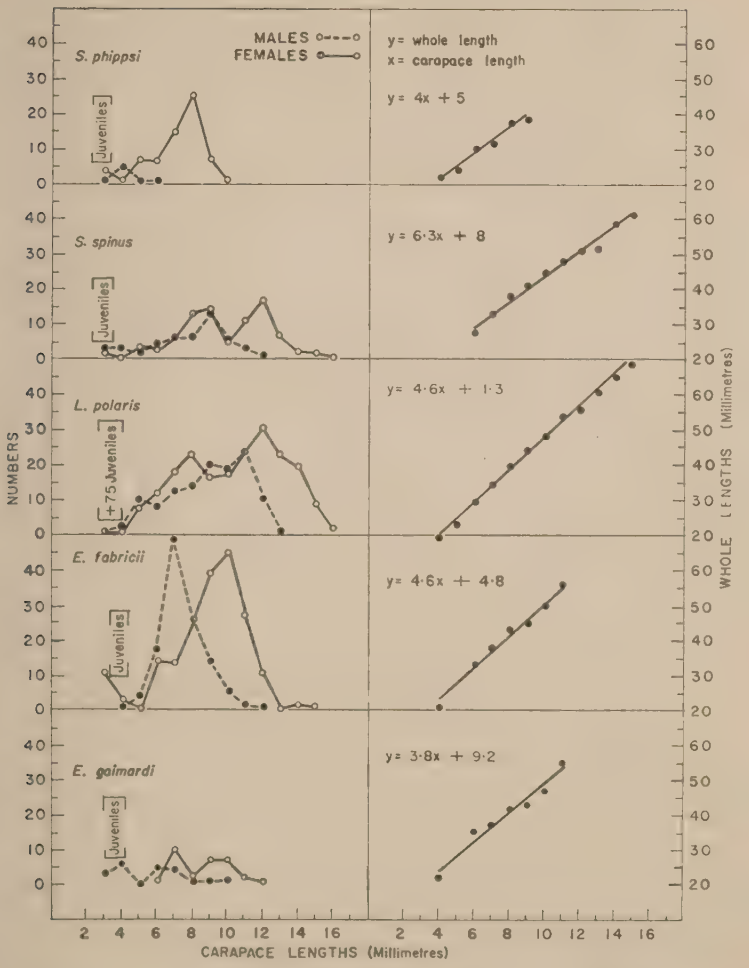

FIG. 3. Carapace length frequencies and regression curves for conversion of carapace lengths to whole lengths in *Spirontocaris phippsi*, *Spirontocaris spinus*, *Lebbeus polaris*, *Eualus fabricii*, and *Eualus gaimardi*. *Calanus* Expeditions in Ungava Bay, 1947 to 1950.

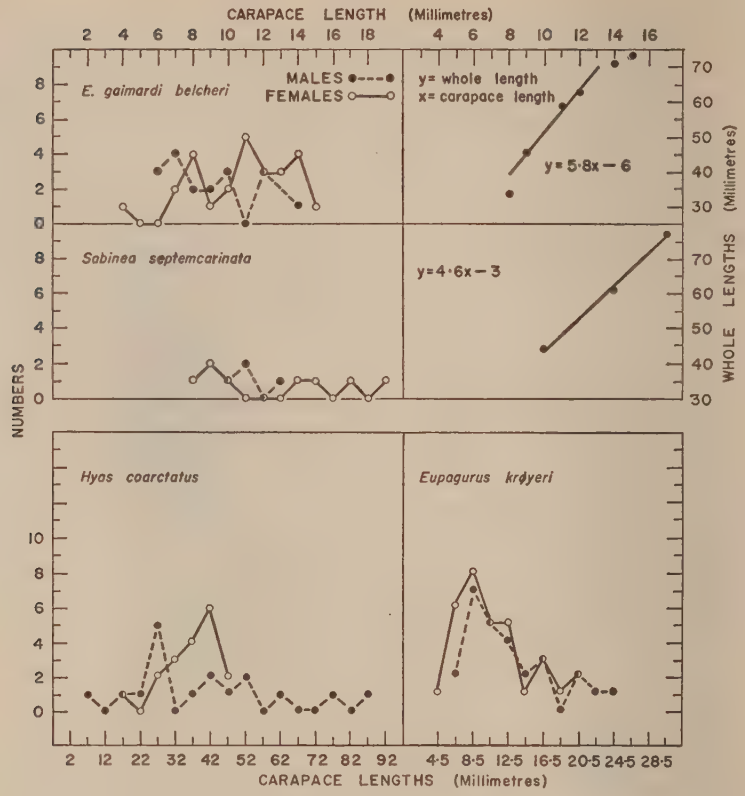

FIG. 4. Carapace length frequencies and regression curves for conversion of carapace lengths to whole lengths in *Eualus gaimardi belcheri* and *Sabinea septemcarinata*; and carapace length frequencies of *Hyas coarctatus* and *Eupagurus krøyeri*. *Calanus* Expeditions in Ungava Bay, 1947 to 1950.

shrimp seems to show a similarity with other marine animals of which some fishes are notable examples. This follows from the fact that the males mature at a somewhat smaller size (Table IV), and possibly earlier age than females, and growth is slower as a consequence thereafter (Templeman and Squires, 1956 (17)).

The shrimp, *Pandalus montagui*, presents a special case where the animals are protandrous (Thorson, 1946 (18, p. 325)). No males taken exceeded 18 mm. in carapace length, and females taken were not less than 20 mm. in carapace length, and reached an extreme length of 25 mm. (Fig. 2).

The largest specimens of shrimp taken belonged to the species *Pasiphaea tarda*, with carapace lengths of 27 to 42 mm. The smallest and, incidentally, most numerous specimens were in the family Hippolytidae, of which *Spirontocaris phippsi* (3 to 10 mm. carapace length) and *S. spinus* (3 to 15

TABLE IV

CARAPACE LENGTHS AND AVERAGE EGG DIAMETER (MM.) IN OVARY OF SHRIMP COLLECTED BY THE *Calanus* EXPEDITIONS IN UNGAVA BAY, 1947 TO 1950, AND INDICATION OF FIRST MATURITY (EGG DIAMETER IN ITALICS INDICATES LENGTH AT WHICH FEMALES OF EACH SPECIES WERE OBSERVED TO BE FIRST MATURE. AN ASTERISK INDICATES THE LENGTH AT WHICH MALES OF EACH SPECIES WERE OBSERVED TO BE FIRST MATURE; NUMBER IN PARENTHESES = NUMBER OF INDIVIDUALS FROM WHICH EGGS WERE MEASURED)

Species	Carapace lengths, mm.																						
	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Pandalus montagui	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.0 (2)	—	—	—
Spirontocaris phippsi	—*	0.3 (2)	*0.4* (3)	0.5 (7)	0.5 (5)	0.5 (1)	1.1 (1)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Spirontocaris spinus	—	—	0.3* (2)	0.3 (3)	*0.5* (4)	0.3 (11)	0.5 (4)	0.6 (8)	0.7 (15)	0.8 (6)	0.3 (1)	0.5 (2)	—	—	—	—	—	—	—	—	—	—	—
Lebbeus groenlandicus	—	—	—	—	0.3 (4)	0.4 (3)	0.5* (5)	0.4 (5)	0.4 (4)	0.5 (6)	*0.7* (6)	1.1 (4)	1.4 (5)	1.2 (4)	0.9 (14)	1.0 (6)	1.1 (3)	0.8 (1)	2.0 (3)	1.3 (1)	—	—	—
Lebbeus polaris	—	—	0.6 (4)	0.4 (12)	0.4* (14)	0.3 (6)	*0.7* (12)	0.7 (13)	1.0 (25)	0.9 (20)	1.0 (17)	0.9 (10)	0.4 (2)	—	—	—	—	—	—	—	—	—	—
Eualus fabricii	—	—	—*	0.3 (5)	*0.4* (6)	0.5 (8)	0.7 (18)	0.6 (10)	0.4 (2)	0.3 (1)	0.5 (1)	—	—	—	—	—	—	—	—	—	—	—	—
Eualus gaimardi	—	—	0.3 (1)	0.3* (4)	0.3 (2)	0.3 (3)	*0.3* (4)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Eualus gaimardi belcheri	—	—	—	—	0.3 (2)	—*	0.3 (1)	0.3 (5)	*1.3* (1)	0.7 (2)	1.2 (4)	0.5 (1)	—	—	—	—	—	—	—	—	—	—	—
Eualus macilentus	—	—	—	—	—	—	—	0.8 (1)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Argis dentata	—	—	—	—	0.2 (2)	0.4* (3)	0.4 (2)	0.3 (1)	0.4 (1)	0.3 (6)	0.2 (4)	—	*0.4* (4)	1.1 (2)	1.0 (2)	1.6 (5)	—	1.7 (2)	0.6 (1)	—	—	—	—
Sclerocrangon boreas	—	—	—	—	—	0.3* (1)	—	—	0.4 (1)	—	—	—	—	—	—	—	—	—	—	1.0 (1)	—	—	1.5 (1)
Sabinea septemcarinata	—	—	—	—	—	—	0.3* (1)	—	—	—	*1.3* (1)	—	—	—	—	—	—	—	—	—	—	—	—

mm. carapace length) were the smallest. *Lebbeus groenlandicus* (5 to 25 mm. carapace length) was the largest hippolytid. In the specimens examined *Eualus gaimardi* was somewhat smaller (3 to 12 mm. carapace length) than its closely related form *E. gaimardi belcheri* (6 to 15 mm. carapace length). Specimens belonging to the family Crangonidae compare in size with the largest hippolytid; its most abundant species, *Argis dentata*, which ranges in carapace length from 4 to 25 mm. and *Sclerocrangon boreas* (6 to 29 mm. carapace length) were among the largest specimens of shrimp taken in the shallow areas of Ungava Bay.

Maturities

Gross approximation of maturity was made from diameter of eggs in ovary or on pleopods, and size of appendices masculinae compared with appendices internae (Chace, 1940 (1)). Some shrimp which had eggs on the pleopods in June also had large eggs in the ovary which would be extruded, undoubtedly, later in the season; however, some which were ovigerous in July and had but small eggs in the ovary were presumed to have just spawned, and would carry eggs through the following winter. Most species had spawned by July, although some specimens collected in September still had large eggs in the ovary (Table V). Generally, smaller or first maturing females spawned earlier in the year than larger females that were presumably already ovigerous in early summer. There was evidence that mature females spawned each year: some with the ovary full of large eggs also had eggs on the pleopods which evidently had not yet hatched. Most early stage larvae were taken in June and July only.

The largest eggs in these species were carried by *Sclerocrangon boreas* (3.1 mm., average diameter in eggs from seven specimens) and *Pasiphaea tarda* (2.7 mm., average diameter in eggs from six specimens). Among shrimp the smallest eggs were carried by *Eualus* and *Spirontocaris* (about 1.2 mm. average egg diameter in 47 specimens), which were the smallest species present in general. *Lebbeus groenlandicus* and *L. polaris*, also in the family Hippolytidae, had larger eggs than *Eualus* or *Spirontocaris* (about 2.2 mm. average egg diameter in 48 specimens). The crangonids *Argis* and *Sabinea* both had eggs about 2.0 mm. in average diameter in four specimens examined. The hermit crabs (*Eupagurus*) and spider crabs (*Hyas*) had eggs which averaged less than 1.0 mm. in diameter in 10 and 15 specimens, respectively (Table VI).

Large shrimp in any species appeared to have larger eggs than small shrimp (Table VI) but it was observed generally that eggs were, presumably, somewhat less in diameter when first extruded than later, and were largest previous to hatching, namely, when there were large eggs in the ovary as well as on the pleopods (Table V). A considerable number of larger shrimp taken in the earlier months carried eggs spawned the previous year: these eggs were large. Large shrimp taken later in the year sometimes carried slightly smaller eggs.

TABLE V

AVERAGE EGG DIAMETERS (MM.) IN OVARY AND ON PLEOPODS OF SHRIMP AND CRABS COLLECTED BY THE *Calanus* EXPEDITIONS IN UNGAVA BAY, JUNE TO SEPTEMBER, 1947 TO 1950 (NUMBER IN PARENTHESES = NUMBER OF INDIVIDUALS FROM WHICH EGGS WERE MEASURED)

Species	June		July		August		September		Av. egg diameter on pleopods
	In ovary	On pleopods	In ovary	On pleopods	In ovary	On pleopods	In ovary	On pleopods	
Pasiphaea tarda	—	—	—	—	0.2 (1)	2.6 (5)	2.5 (1)	3.0 (1)	2.7
Pandalus montagui	—	—	1.0 (2)	—	—	—	—	—	—
Spirontocaris phippsi	—	—	0.4 (11)	1.4 (5)	0.6 (8)	1.2 (5)	—	1.4 (2)	1.3
Spirontocaris spinus	0.4 (1)	1.4 (1)	0.5 (32)	1.4 (11)	0.6 (23)	1.5 (5)	—	—	1.4
Lebbeus groenlandicus	0.3 (2)	—	0.9 (49)	2.3 (7)	0.6 (20)	2.0 (1)	1.8 (3)	—	2.2
Lebbeus polaris	0.5 (3)	2.0 (1)	0.8 (96)	2.2 (24)	0.8 (21)	2.0 (10)	0.5 (15)	2.0 (5)	2.1
Eualus fabricii	0.9 (1)	—	0.6 (30)	1.2 (2)	0.4 (16)	1.2 (8)	0.4 (4)	0.9 (3)	1.1
Eualus gaimardi	—	—	0.3 (3)	1.0 (1)	0.3 (10)	1.2 (4)	0.3 (1)	—	1.2
Eualus gaimardi belcheri	—	—	0.7 (15)	—	0.3 (1)	1.3 (1)	—	—	1.3
Eualus macilentus	—	1.2 (1)	0.8 (1)	—	—	—	—	—	1.2
Argis dentata	—	—	0.7 (31)	2.0 (3)	0.7 (7)	—	—	—	2.0
Sclerocrangon boreas	—	—	0.4 (2)	3.0 (1)	1.3 (2)	3.3 (2)	—	3.1 (6)	3.1
Sabinea septemcarinata	—	—	0.3 (1)	—	1.3 (1)	2.0 (1)	—	—	2.0
Eupagurus krøyeri	—	0.9 (2)	—	0.9 (5)	—	0.9 (3)	—	—	0.9
Hyas coarctatus	—	—	—	0.7 (4)	0.8 (1)	0.7 (11)	—	—	0.7

TABLE VI

AVERAGE EGG DIAMETER (MM.) ON PLEOPODS OF SHRIMP AT EACH CARAPACE LENGTH COLLECTED BY THE *Calanus* EXPEDITIONS IN UNGAVA BAY, 1947 TO 1950 (NUMBER IN PARENTHESES IS NUMBER OF INDIVIDUALS FROM WHICH EGGS WERE MEASURED)

Species	Carapace lengths, mm.																					Range of egg diameters, mm.	Av. egg diameter, mm.
	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	24	25	26	27	28		
Spirontocaris phippsi	1.3 (1)	1.3 (3)	1.4 (7)	—	1.5 (1)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.1–1.5	1.3
Spirontocaris spinus	—	—	1.2 (2)	1.4 (2)	1.4 (3)	1.5 (1)	1.5 (3)	1.6 (3)	1.6 (1)	1.6 (1)	1.4 (1)	—	—	—	—	—	—	—	—	—	—	1.0–1.8	1.4
Lebbeus groenlandicus	—	—	—	—	—	—	—	—	—	—	—	—	2.2 (5)	2.3 (2)	2.4 (1)	—	—	—	—	—	—	2.0–2.4	2.2
Lebbeus polaris	—	—	—	—	—	2.0 (5)	2.1 (10)	2.2 (11)	2.1 (8)	2.1 (4)	2.3 (2)	—	—	—	—	—	—	—	—	—	—	1.8–2.4	2.1
Eualus fabricii	—	—	—	1.2 (3)	1.1 (6)	1.2 (1)	0.9 (2)	1.2 (1)	—	—	—	—	—	—	—	—	—	—	—	—	—	0.9–1.2	1.1
Eualus gaimardi	—	—	—	—	1.2 (3)	1.1 (2)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.0–1.2	1.2
Eualus gaimardi belcheri	—	—	—	—	—	—	1.3 (1)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.3	1.3
Argis dentata	—	—	—	—	—	—	—	—	—	—	—	—	—	2.0 (1)	—	2.0 (2)	—	—	—	—	—	2.0	2.0
Sclerocrangon boreas	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3.0 (2)	3.0 (2)	3.3 (2)	3.1 (2)	3.5 (1)	2.9–3.5	3.1

Assessment of the Decapod Fauna of Ungava Bay as Shown by the *Calanus* Expeditions Collections

The percentage of dredgings, etc., which took decapods was very high (average 95%) in the 1947 to 1950 *Calanus* Expeditions in Ungava Bay. The percentage of stations at which decapod larvae were taken in plankton hauls was also high (average 85%, Fig. 5). The presence of many specimens in stomach contents of fish and seals also attests the considerable quantity of decapods and their importance in the bionomics of the area.

In comparison with adjacent areas, Ungava Bay has a decapod fauna similar to that of the shallow water areas of west Greenland and has a few subarctic–boreal elements not found in the Hudson Bay area, as far as is known from collections in these areas. Ungava Bay also shows some incursion from the east of deep water pelagic species, notably, *Pasiphaea tarda* and *Sergestes arcticus*. These species were taken near Port Burwell and Resolution Island and evidently do not range far into Hudson Strait. Other deep-water pelagic species of Davis Strait and west Greenland have not been taken in the present collections. Although current movements are predominantly out of the bay and southward along the Labrador coast (Dunbar, 1951 (3)), there is evidence of Atlantic water in Ungava Bay from hydrographic and plankton results already discussed in this series (Fontaine, 1955 (6)). The presence of *Pasiphaea* and *Sergestes* in the *Calanus* Expeditions collections in this area, 1947 to 1950, supports such a conclusion.

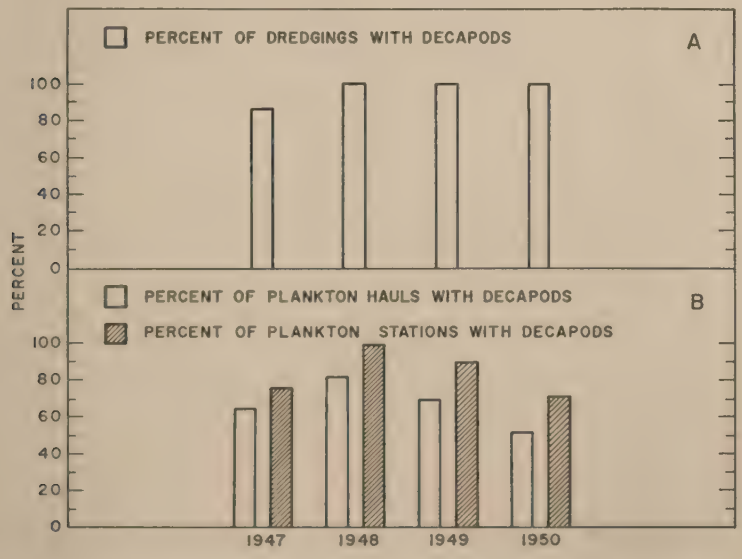

FIG. 5. Percentage of dredgings (A), and percentage of plankton hauls and plankton stations (B), in which decapods were taken in Ungava Bay by the *Calanus* Expeditions, 1947 to 1950.

The more typical decapod fauna of Ungava Bay is represented by such species as *Argis dentata*, *Lebbeus groenlandicus*, *L. polaris*, *Eualus fabricii*, *Spirontocaris spinus*, *Sclerocrangon boreas*, *Eupagurus krøyeri*, and *Hyas coarctatus*. These were taken in considerable numbers in dredgings, etc., and as a major constituent of the stomach contents of fish and seals in Ungava Bay, and were well-distributed throughout the area explored. Larvae, also, of these species (except *Sclerocrangon*, which does not have pelagic larvae) were taken in considerable numbers in plankton hauls. No larvae of *Sergestes* or *Pasiphaea* were taken in the Bay or area explored near its entrance during 1947 to 1950.

Two dominant forms in the area, *Argis dentata* and *Lebbeus groenlandicus*, have originated in the Pacific (Stephensen, 1935 (15)), and it is easy to see that Ungava Bay can be more readily populated by the spreading of species from the west because of water movements (Dunbar, 1951 (3)). Other Pacific species, *Eualus fabricii* and *E. macilentus*, are represented in these collections, although *Chionoecetes opilio* is not: the latter may be restricted to deeper water than was explored by the *Calanus* Expeditions in Ungava Bay. Decapods defined by Stephensen (1935 (15)) as exclusively high arctic are deep water species and presumably would not be found in the shallow water areas of Ungava Bay; this would apply to other deep water but subarctic and boreal species found in nearby waters to the east. Circumpolar species, *Lebbeus polaris*, *Spirontocaris phippsi*, *S. spinus*, and *Sclerocrangon boreas* are well-represented in these collections. Subarctic–boreal species of the North Atlantic, *Hyas coarctatus*, *S. lilljeborgi*, and *Pandalus montagui*, are also found in the northern Pacific or the waters north of Behring Strait (Stephensen, 1935 (15)) so that they, too, may have reached Ungava Bay from the west. Larvae of *Hyas* were in large numbers in plankton hauls taken by the *Calanus* Expeditions, 1947 to 1950. The pelagic Atlantic species *Sergestes* and *Pasiphaea* taken at the entrance to Ungava Bay may possibly be considered as accidentals.

A decapod, presumably not from the Pacific but an Atlantic species extending from America to northern Europe (Rathbun, 1929 (12)), which is extremely well-established in Ungava Bay, as shown particularly by the large numbers of larvae taken in plankton hauls, is the hermit crab, *Eupagurus krøyeri*. Unfortunately, there is some controversy over its identity as a species. Hansen (1908 (8)) believed that *E. krøyeri* was synonymous with *E. pubescens* and perhaps *E. trigonocheirus* (which is a Pacific form taken north of Alaska; MacGinitie, 1955 (11)). Until this controversy is resolved no conclusions about *E. krøyeri* can be drawn.

Summary

1. Comparison of decapod species taken in Ungava Bay by the *Calanus* Expeditions with those taken in the west Greenland – Davis Strait area shows that there is close similarity particularly between the decapod fauna of Ungava Bay and that of the shallow water areas of west Greenland.

2. A compiled key for all species collected and their closely related forms emphasizes numbers of exopods, epipods, etc., since these characters help to identify damaged specimens from stomach contents of fish and seals.

3. Systematics of the 17 species collected is treated under occurrence in Ungava Bay, world distribution, and taxonomy—the latter referring mostly to variable characters such as number of spines on rostrum, carapace, and telson.

4. *Pasiphaea tarda* and *Sergestes arcticus*, deep-water pelagic forms of the Davis Strait – west Greenland area, were taken for the first time near the entrance to Ungava Bay.

5. *Eualus gaimardi* and its closely allied form *E. g. belcheri* were found in similar areas in Ungava Bay. A northern trend towards the form *belcheri* is shown not to apply in consideration of specimens from this collection and others in the northwestern Atlantic.

6. *Argis dentata* as defined by Rathbun was found to be the sole species of this genus in Ungava Bay, and since Dr. Rathbun named specimens from Greenland *Argis dentata*, the distribution of *A. lar* east of Alaska is questioned.

7. A constant character of a double spine in the center on the carapace was present in *Sclerocrangon boreas* and generally the spines were larger than on the typical form. However, in view of intergradations and similar specimens from areas widely separated, no new species naming was proposed.

8. The *Calanus* Expeditions, 1947 to 1950, took *Eualus macilentus* and *Sabinea septemcarinata* in Ungava Bay for the first time that has been recorded.

9. Ratio of carapace length to rostrum length showed that the specimens of *Hyas coarctatus* examined were the typical form of the species and not the form *alutaceus*.

10. Equations were calculated to convert carapace lengths to whole lengths in most species of shrimp represented.

11. Lengths of females exceeded those of males in range in all species of shrimp except *P. tarda*, and the converse was seen to apply in hermit and spider crabs.

12. *P. tarda* was the largest species of shrimp taken by the *Calanus* Expeditions, 1947 to 1950; but *L. groenlandicus*, *A. dentata*, and *S. boreas* were all of fair size and abundance in the shallow areas of the bay.

13. Male shrimp were found to mature at a much smaller size than did first mature females, which probably accounted for their smaller size in general.

14. Spawning seemed to take place earlier in the year in first maturing females—some ovigerous in June and July—than in larger mature females, whose eggs hatched mostly in June and July, and which did not spawn until August or September, for the most part.

15. Egg size varied somewhat in a species; eggs just spawned appeared to be smaller, generally (all were measured from about 7% formalin).

16. Largest eggs were carried by *Sclerocrangon* (3.1 mm. average diameter) and *Pasiphaea* (average 2.7 mm.); *Lebbeus* had eggs 2.0 to 2.5 mm., *Spirontocaris* 1.2 to 1.4 mm., *Eualus* 1.0 to 1.2 mm., *Argis* and *Sabinea* about 2.0 mm.

APPENDIX

TABLE VII

NUMBERS OF SPECIMENS OF EACH SPECIES OF DECAPOD CRUSTACEANS TAKEN BY DIFFERENT MEANS IN UNGAVA BAY BY THE *Calanus* EXPEDITIONS, 1947 TO 1950

Species	Dredge and beam-trawl	Stramin (touched bottom)	No. 6	No. 0	No. 00 No. 5	Shrimp net	Stomach contents of: Cod	Ringed seal	Bearded seal	Harbor seal	Harp seal	Sculpin	By hand	Total
Sergestes arcticus	—	—	—	—	—	88	174	1	—	—	4	—	—	267
Pasiphaea tarda	—	—	—	—	—	—	46	—	—	—	—	—	—	46
Pandalus montagui	11	3	—	—	—	—	37	29	1	—	—	—	—	81
Spirontocaris lilljeborgi	—	—	—	—	—	—	—	—	2	—	—	—	—	2
Spirontocaris phippsi	24	21	—	—	—	—	18	32	36	6	—	—	—	137
Spirontocaris spinus	77	34	—	—	—	—	47	3	21	3	—	—	—	185
Lebbeus groenlandicus	159	7	—	—	—	2	40	14	176	15	—	—	—	413
Lebbeus polaris	211	23	—	—	125	19	69	13	8	5	—	—	—	473
Eualus fabricii	173	44	—	—	39	6	70	37	27	20	—	—	—	416
Eualus gaimardi	34	1	4	3	—	1	33	23	3	—	—	—	—	102
Eualus gaimardi belcheri	23	6	—	—	—	—	7	3	6	1	—	—	—	46
Eualus macilentus	1	—	—	—	—	—	—	3	—	—	—	—	—	4
Argis dentata	67	—	—	—	—	—	7	6	253	7	—	—	—	340
Sclerocrangon boreas	9	—	—	—	—	—	1	39	174	4	—	—	—	227
Sabinea septemcarinata	4	—	—	—	—	—	7	—	1	—	—	—	—	12
Eupagurus krøyeri	60	1	—	—	—	—	9	—	—	—	—	—	—	70
Hyas coarctatus	37	—	—	—	—	—	10	1	20	4	—	3	3	78
Hippolytid	1	—	—	—	—	—	2	16	27	78	—	—	—	124
Decapod	—	—	—	—	—	—	—	33	18*	—	1	—	—	52
Totals	891	140	4	3	164	116	577	253	773	143	5	3	3	3075

*Many in addition were in smaller fragments and could not be counted.

ional Report for Canada

CEANOGRAPHY IN CANADA
54-57

TERNATIONAL UNION OF
ODESY AND GEOPHYSICS
TERNATIONAL ASSOCIATION
PHYSICAL OCEANOGRAPHY
EVENTH GENERAL ASSEMBLY
RONTO, CANADA, 1957

compiled by
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Canadian Joint Committee on Oceanography

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CANADIAN OCEANOGRAPHY 1954-57

by

H. B. HACHEY
Chief Oceanographer
Fisheries Research Board of Canada

TRODUCTION

Oceanography in Canada has been, for the past ten years, ·ordinated under the Canadian Joint Committee on Oceanography. is Committee is a planning and co-ordinating body, comprising, shown on the organization list, representatives of the Royal nadian Navy, the Fisheries Research Board, the Defence Research ard, the National Research Council, the Hydrographic Service, and Meteorological Service. Several advisers assist the Committee th their specialized knowledge relating to fisheries and defence oblems.

The Royal Canadian Navy provides, maintains, and operates o oceanographic vessels, one on the east coast and one on the st coast. During the past few years, the Navy has also provided ilities for Arctic research on board the modern ice-breaker, the M.C.S. *Labrador*. Ships are also made available, on occasion, for tended programs beyond the scope of the oceanographic vessels. e Fisheries Research Board furnishes the required personnel, the ministrative facilities, and the shore laboratories. The require- nts in oceanography for fisheries, naval and other national erests are incorporated into the program of the Fisheries Research ard's Atlantic and Pacific Oceanographic Groups, located respect- ly at its Biological Stations at St. Andrews, N.B., and Nanaimo, C.

The field activities of the Board's Biological Stations, of the nadian Hydrographic Service, and of the Naval Research Labora- ies of the Defence Research Board are, in some phases, closely ied with the activities co-ordinated under the Joint Committee, d close liaison and co-operation are maintained. The National search Council takes an active interest in the general development the subject of oceanography in Canada, in part through the repre- ntation on the Joint Committee and in part through its Associate mmittee on Geodesy and Geophysics.

The National Research Council and the Defence Research Board ve given continued support to the establishment of the Institute Oceanography at the University of British Columbia. Grants-in- d and scholarships are available from the National Research

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Council, the Fisheries Research Board, and the Defence Research Board to encourage various fundamental studies, and to assist graduate students proceeding to higher degrees with specialization in some branch of oceanography.

A Royal Society of Canada Committee on Oceanography is active in creating a broader national interest in the scientific problems of the sea, and has organized symposia and joint sessions on oceanographic subjects. The Nova Scotia Research Council has contributed in a similar manner by organizing conferences dealing with problems of the sea.

The Meteorological Service of Canada has long been interested in problems of maritime meteorology, a subject that became of increasing practical importance with the development and expansion of trans-ocean flying. Recently the Service has extended its activities into sea-ice forecasting, and in this field a study of oceanographic factors is a most important one.

Developments under the Joint Committee

Previous to World War II, oceanographic activities in Canada were prosecuted on a small scale in relation to fisheries (Fisheries Research Board), to navigation (Hydrographic Service), and to meteorology (Meteorological Service). The number of oceanographers in Canada was small, and the knowledge of Canadian waters generally was very meagre. It was appreciated that real progress in the post-war years would follow from the co-ordinated efforts of various departments of the government. The lack of trained personnel was an outstanding limiting factor, and every effort has been made to deal with this problem. Some considerable progress has been made in training personnel, in part due to the realistic attitude adopted by the organizations represented on the Joint Committee and in part due to the activities of the Institute of Oceanography of the University of British Columbia. The availability of trained personnel has not however kept pace with the modest expansion of the oceanographic programs under the Joint Committee, or even with the special requirements of the Hydrographic Service, the Meteorological Service, and the Defence Research Board. Potential oceanographers have been attracted into other fields and in some few cases to other countries. In retrospect, however, a group of young and enthusiastic oceanographers well trained in fundamentals is now available, and modest future progress in this respect might be expected.

The past several years have seen the development of programs to meet the requirements of national agencies, and the subject of oceanography has attained scientific recognition in Canada. More than one hundred scientific papers, and over one hundred manuscript reports for internal distribution on oceanographic subjects have been published by the two Oceanographic Groups since the inception of the Joint Committee. Other papers have originated with other agencies, notably the Defence Research Board, the Hydro-

ıphic Service, and the Meteorological Service. Investigational ·as have expanded to give coverage to all water areas of Canadian erest.

e Canadian Oceanographic Problem

Canada has an enormous coast line, east, north and west, and s a specific interest in oceanographic problems concerned with ıeries and defence in the waters extending outwards many miles all three coasts. Canada is committed to the activities of com-ssions involved in the regulation, prosecution, and preservation fisheries which are international in scope. She has as well many ɔblems related to her inshore fisheries of particular Canadian ıcern. A full understanding of these fisheries for proper manage-nt requires a knowledge of the environment, and this in itself ll, for many years yet, require observations directed towards taining basic knowledge of the waters of the three oceans, Atlantic, cific and Arctic. Superimposed upon this observational work is e need for study of the fundamental processes which determine d control the environment that governs the welfare of the different ecies of fish. The oceanographic requirements for navigation and fence also demand widespread observations to supplement our esent knowledge. There are as well many other aspects of nadian development which require a knowledge of our ocean ters. Problems arise in connection with the laying of telephone, egraph and transmission cables; with pollution, shore erosion and ilding processes; with marine meteorology, sea ice, and ocean ve problems; with the extraction of chemicals from the sea; and ıost of others.

The task of dealing with these problems is a formidable one, d where various national agencies are involved, the Joint Com-ttee on Oceanography has demonstrated that the best progress can made through the co-operation of the various agencies, and the oling of resources of personnel, ships, and equipment.

lantic Oceanography, 1954-57

On the Atlantic Coast the main water body of particular Cana-an concern is contained within the area of confluence of two great ean systems, the Gulf Stream and the Labrador Current. Thus e characteristics of the waters which are found on our eastern ıboard are determined in the main by the mixing and layering of ntributions from these two water masses, and modified in the astal area by contributions from land drainage systems. Of the nd drainage systems, that of the St. Lawrence predominates. ntinental weather plays a role in determining the physical and emical characteristics of these waters, but in the main, the water dy reflects the varying relative influences of Gulf Stream, Labrador, d continental waters.

In this Atlantic area, continued attention has been given to a udy of the waters of the Bay of Fundy, Scotian Shelf, the Gulf of

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St. Lawrence, the Grand Banks, and the Labrador Sea. Oceanographic cruises have been conducted by the Atlantic Oceanographic Group and the Biological Stations of the Fisheries Research Board, the Hydrographic Service and the Naval Research Establishment of the Defence Research Board. Canadian observations in the period reported upon have been supplemented by those of the International Ice Patrol, the Woods Hole Oceanographic Institution, the U.S. Fish and Wildlife Service, the U.S. Hydrographic Service, the *Blue Dolphin* Expeditions, and by the fishery research ships of the European nations which prosecute the great fisheries of the Grand Banks and Greenland waters.

The combined efforts have contributed to our knowledge of these waters, relative to the distribution of temperature, salinity, oxygen and nutrients; to seasonal and long term variations in some of these characteristics; and to circulation patterns, mixing processes, and interrelations between sea and atmosphere. The general surveys have been supplemented by daily observations at selected stations, and by fundamental studies of the Gulf Stream, Labrador Current, Slope Waters, and the Gaspé Current. In the winters of 1956 and 1957, the first oceanographic winter cruises of the Gulf of St. Lawrence were carried out, initiating studies on the factors involved in the production of the typical cold water, and in the formation, movement and deterioration of ice.

The upward trend of surface water temperatures which has persisted for the past twenty-five to thirty years, with some amelioration in the period 1940-50 and with greater emphasis during the past five years, is now showing a reversal. Bottom water temperatures over the Scotian Shelf still remain high in comparison with those of earlier years, by as much as from one to three degrees Centigrade in the eastern sector, and from two to three degrees on LaHave Bank. Analysis has shown that the tendency towards higher bottom water temperatures on the Scotian Shelf is associated with a warmer and thinner "intermediate layer", indicating that the influence of more northern waters is not as intensive in recent years.

A subject of a continuing investigation has been the slope water off the continental shelf, a band of warm, saline water lying between the coastal water and the Gulf Stream. These waters have a profound effect upon the coastal regime through incursions of slope water on the shelf and through modification of the coastal waters in their southwestern drift along the shelf. It has been shown that slope water is formed from the mixture of Atlantic and Coastal waters in the proportion of 3.8 to 1, and that the deeper coastal waters are formed by a mixture of Labrador and slope waters. Convincing evidence has been obtained to establish that a major east-flowing current originates in the slope water area to the southwest of the Grand Banks.

Currents and transport of volume and salt have been calculated by dynamical methods for Cabot Strait in a section extending from Cape North, Cape Breton Island, to Cape Ray, Newfoundland. Analyses have been made of eight crossings of the section. The current distribution showed much variation from cruise to cruise, with the

ongest currents in August and the weakest in April and May. The rrents were outward on the Cape Breton side and most often ward on the Newfoundland side, and reversals with depth having fixed patterns were found. Inward and outward transports rough the section were found to be of the order of one million bic metres per second and to vary considerably.

Studies of the deep water in the Laurentian Channel within e Gulf of St. Lawrence have shown that the deep layer consists a mixture of "Labrador" and "Slope" water in which the mixing tio of the components remains fairly constant from year to year. us, fluctuations in temperature of "Labrador" water are reflected corresponding changes in the temperature of the deep layer in e Laurentian Channel. The upward trend of temperatures is companied by a greater volume of the deep layer.

The results of winter surveys in the Gulf of St. Lawrence have own that reasonable forecasts of ice conditions can be made from consideration of the "ice potential", as calculated from late autumn rveys, and subsequent meteorological records. They have also rown some light on the source of the intermediate cold water yer in the Gulf. The volume of this cold water varies from year year and it is now estimated that at least half of this layer is formed the Gulf and is the result of winter chilling *in situ*.

rctic Oceanography, 1954-57

A considerable effort has been expended by the Atlantic Oceanraphic Group in the H.M.C.S. *Labrador* over a period of three ars, in studying the oceanography of the waters of the Canadian rctic. This effort was supplemented by the Canadian–United ates Expedition to the Beaufort Sea in 1954 which involved the fence Research Board, the Pacific Oceanographic Group, and the ited States Navy. On a smaller scale, oceanographic observations re made by the Arctic Unit of the Fisheries Research Board in e M. V. *Calanus* in Hudson Bay and Strait, and in Foxe Basin. e Hydrographic Service in the M. V. *Theron* and the M. V. *Algerine* ade observations during this three-year period in Ungava Bay and dson Bay.

In 1954, the *Labrador* centered its northern operations at Reso-te on Cornwallis Island, and made various cruises to cover northern ffin Bay and the various sounds, straits and passages to the north d east. In the late summer, the *Labrador* made the east-to-west ssage from the Atlantic to the Pacific through Lancaster Sound, rrow Strait, Viscount Melville Sound, and Prince of Wales Strait. e Canadian–United States Expedition to the Beaufort Sea in the S.S. *Burton Island* and the U.S.C.G.C. *Northwind* made the west-t-east passage through McClure Strait, and joined up with the *brador* in passing through Prince of Wales Strait to the Beaufort a. Observations from these combined efforts included measure-ents of temperature, salinity, oxygen, phosphate and silicate. thythermograph recordings and bottom samples were also obtained. rrent measurements were made at all available opportunities.

Several long series of current profiles at anchored stations were obtained, and two ships occupied stations in Bering Strait simultaneously over a period of eight hours.

In 1955, the *Labrador* made an extensive coverage of the waters of Hudson Strait and Foxe Channel and Basin. The *Calanus* arrived in Foxe Basin in late summer and wintered there, maintaining an oceanographic station for a complete year near Igloolik Island. The Hydrographic Service occupied stations in Ungava Bay and Hudson Bay during the late summer season.

In 1956, the *Labrador* again made an extensive coverage of Hudson Strait and Foxe Basin. Towards the end of the season, the ship passed northward through Fury and Hecla Strait. Oceanographic sections were made in Committee Bay, Gulf of Boothia, Prince Regent Inlet, and Lancaster Sound. Ice studies were made in association with the McGill Group under the auspices of the Defence Research Board. The work in Foxe Basin was supplemented by that of the *Calanus*. Ships of the Hydrographic Service occupied further stations in Ungava Bay and Hudson Bay.

As a result of the past two seasons' work, the dynamics of Hudson Strait, Foxe Channel and Basin are now fairly well known for the summer and autumn months. The circulation of Hudson Strait is dominated by a steady outflow of water from Hudson Bay which is confined largely to the south shore. The main outflow from Hudson Bay appears to be between Cape Wolstenholme and Nottingham Island. The stream parallels the coast as far as Ungava Bay and is approximately 20 to 30 miles in width. The inflowing waters around Resolution Island appear to be more variable. A definite movement of water along the Baffin coast extends into the Strait. This water turns into the main outflowing stream between Akpatok and Big Island. Part of the exchange of water in the eastern section of the Strait occurs directly between the eastern passages and Ungava Bay. The westward flow along the north side of the Strait practically ceases at Big Island where an eastward flow from Hudson Bay also appears to terminate. A return circulation westward along the north coast to Foxe Channel exists. This current must carry some of the water, which originally entered the Strait off Resolution Island, into Foxe Channel and Hudson Bay.

Two main current features appear in Foxe Basin, a strong southerly movement of water along the western side extending from Fury and Hecla Strait to the southeast tip of Southampton Island, and a northerly flow up the central part of Foxe Channel. The southerly flow also maintains an outflow of water through Frozen Strait and a large back eddy in the central part of the Basin. The northerly movement of water appears to originate in Hudson Bay and Hudson Strait and extends well into the Basin, turning eastward around Foxe Peninsula.

The movements of Foxe Basin ice in relation to navigation in Hudson Strait has always been a matter of some concern. The break-up in Foxe Basin begins about mid-June with formation of leads off Foxe Peninsula and relatively open water at the eastern

ıd of Fury and Hecla Strait. By late July, the northern open ater has extended south into Parry Bay and the Foxe Peninsula ad has expanded into the shallows south of Prince Charles Island. bout this time, break-up begins along the northeast coast of South- npton Island and continues northward along the western shore the form of leads running parallel to the coast. Most of the ice sses out of the Basin during the latter half of August and the first vo weeks of September. However, the open water in the north comes congested with winter ice passing through Fury and Hecla rait from the Gulf of Boothia and Committee Bay. This ice oves south in the main channel along the western shore, passing ıt through the western section of Foxe Channel into Hudson Strait. y mid-September, Fox Basin is free of ice except for remnants of ıore ice and occasional flows of winter ice which drift in through ury and Hecla Strait. This condition remains from approximately id-September to the middle of November by which time young e is forming rapidly throughout the Basin and Strait.

From these various activities in northern areas, the characteris- cs of the waters of Baffin Bay, the Eastern and Western Arctic, nd the Beaufort Sea have also been outlined. In particular, it has een shown that the salinities of the cold water layer in the Baffin ay area (32.5 to 34.0‰, with a salinity of 33.7‰ associated with ıinimum temperatures of −1.8°C.), are considerably higher than ıose of the Western Arctic and Beaufort Sea (31.5 to 33.0‰, with salinity of 32.3‰ associated with a minimum temperature of -1.8°C.). Of particular significance is a comparatively warm water ıyer lying below the cold water layer, and having an apparent gen- ral distribution in the northern areas where depths are generally reater than 300 metres. The temperatures of this deep warm water ıyer are between 0.5 and 1.3°C. with salinities of approximately 4.5‰. Waters found at 250 metres in the Beaufort Sea, at 500 ıetres in Smith Sound, and 1250 metres in central Baffin Bay have dentical temperature and salinity characteristics (−0.3°C., 34.4‰). t has been demonstrated that deep Baffin Bay water originates in he Arctic Ocean, rather than through local cooling and freezing rocesses.

'acific Oceanography

The bold and rugged Pacific Coast of Canada is indented with nany deep inlets which present water bodies of various magnitudes vith fjord-like characteristics. The oceanography of the immediate oastal seas is dominated by the outflow from the many larger rivers, nd the turbulent currents in many straits and passages. Outside ıf the coastal area, the outstanding circulation of the North Pacific s contained in the North Pacific Current, a part of the Kuroshio ystem. This North Pacific Current is the general eastward flow of varm water to the east of Longitude 160°E. To the north of the North Pacific Current, and centered at about Latitude 50°N., is found ın entirely different subarctic type of water which flows to the ast and which is generally referred to as the Aleutian Current.

One branch of this Aleutian Current flows towards the south before reaching the coast of North America and is known as the California Current. Another branch flows northward into the Gulf of Alaska, and since it comes from the south it has the character of a warm current, although it possesses the characteristics of subarctic water.

The circulation of waters in the area of the eastern North Pacific, between California and the Aleutian Islands, is therefore mainly based on these two branches of the Aleutian Current. In particular, the branch flowing north transports offshore waters towards the British Columbia coast, such transport varying considerable in amount with the changing wind system of the season.

The general Canadian program on the Pacific Coast is carried out by the Fisheries Research Board's Pacific Oceanographic Group and Biological Station located at Nanaimo, B.C. Detailed attention has been given to the Pacific coastal region, including Hecate Strait, the Strait of Georgia, and the Strait of Juan de Fuca. This general program has been supplemented by daily observations of temperature and salinity and general weather at a number of coastal points, and it has been demonstrated that these data provide important indices of oceanographic conditions in these coastal areas.

One phase of an intensive study of the waters of Hecate Strait, which also encompassed those of Queen Charlotte Sound and Dixon Entrance, was brought to a conclusion in June 1956 upon completion of a series of seven bi-monthly oceanographic surveys. These encompassed all parts of the area in all seasons. Temperature, salinity and dissolved oxygen were observed at standard depths from surface to bottom on all surveys. During four cruises, the tidal and non-tidal currents were observed at half-hour intervals throughout a fifty-hour period. As in all northeast Pacific waters, the surface salinity is low, 30 to 32‰. Generally it is least in winter coincident with maximum precipitation. There is a gradient from oceanic salinities, along the seaward side of the area, to lesser values along the mainland shore, and the waters of Dixon Entrance are less saline than those of Hecate Strait. Marked dilution, the effect of land drainage, is found only in the southeast corner where drainage from the coastal inlets is evident in all seasons. To the north, discharge from the Skeena and Nass Rivers is evident in June, and is dispersed northward into the passages of the Alaskan Panhandle. Vertical salinity gradients are small in summer, and absent during the winter season. The annual temperature cycle is greater along the mainland coast (winter 7°C., summer 12°C.) and least along the seaward side (9° to 11°C.). The gradients are small in summer and absent in winter. Currents in the area are primarily due to wind and tide, and one or the other may be dominated from time to time and from place to place. The wind current system is complex, and as tidal intrusion occurs both from the south and the north, the tidal current system is also complex. A hydraulic model of the Hecate Strait region is under construction and it is hoped that model studies will clarify the complex circulation observed.

The recent establishment of the International North Pacific Fisheries Commission, embracing Canada, the United States, and

an, and their subsequent investigations of fisheries problems, has ulted in co-operative oceanographic and fisheries investigations North Pacific waters. During 1955, a joint synoptic oceanographic vey over the Pacific Ocean north of the Tropic of Cancer was ried out during August. One Canadian, seven United States, and nty Japanese ships each surveyed a selected part of the area. s oceanographic survey of an ocean, the largest co-operative anographic operation ever attempted on an ocean-wide basis, s followed in 1956 and February 1957 by the Pacific Oceanographic up's intensive surveys of the area north of Latitude 40°N. and t of Longitude 180°. The Group was ably assisted in these ocean veys by the H.M.C. ships *St. Therese, New Glasgow* and *Oshawa.*

Prior to this survey, the circulation of the North Pacific had n deduced from statistical analyses of reports from ships during past hundred years, from intermittent localized observations, l from theoretical considerations. Preliminary analysis of the ults of the recent surveys during the late summer months shows t there is a boundary gradient between the subtropical water °C. and warmer) and the subarctic water (14°C. and colder). s gradient lies principally between Latitudes 40°N. and 45°N. and ends from the 180° meridian to the North American coast, where urns southward.

This gradient probably outlines the North Pacific Drift Current. e distribution of surface salinities during the late summer months emphasizes the boundary gradient between the subtropical water 4.0‰ and higher) and the subarctic water (32.8‰ and lower). rth of this temperature–salinity gradient, and bounded on the east, th, and west by the North American continent and the Aleutian ain, is the body of water which has been given priority in the tial analysis of the collected data.

In summer, in this subarctic region, there is an upper zone of atively homogeneous low salinity water, less than 33.0‰, extend- to a depth of about 100 metres. This depth is also the lower limit the thermocline which outlines an upper comparatively homo- eous warm layer of about 50 metres in thickness. In the approxi- te center of this region, the colder surface temperatures and the gher surface salinities of the region are found, indicating upward tical transport of water from greater depths.

Within the limits of this subarctic body of water is contained e Alaska Gyral. The horizontal surface gradients of both tem- rature and salinity which form the periphery, and the evidence of ward vertical transport of waters in the central portion, indicate t this body is or has been involved in anti-clockwise rotation. study of the dynamics of this body of water by the Pacific eanographic Group has suggested that the Gyral is wind accele- ed during the prevalence of the winter-type wind circulation October to April). Such winter acceleration on the system causes nsport of surface ocean waters towards the periphery and gives e to upwelling towards the center. This system of circulation rsists throughout the summer months by virtue of its winter-

generated momentum although it is obviously weakened by the summer wind.

The preliminary results of other phases of the investigations have shown high concentration of nutrients and plankton in the central portion of this Gyral, and concentrations of feeding fish on the periphery. This program, on an ocean-wide scale, promises well to offer the final solution to an international fishery problem in the North Pacific.

The Institute of Oceanography of the University of British Columbia has played a leading role in studies that have been made of virtually all of the major British Columbia inlets, involving observations of depth, temperature, salinity, oxygen, and bottom materials. A technique has been developed for estimating from the heat budget the mean seaward flow, and this also yields an estimate of run-off when the salinity is known. This has been applied in a number of cases. Internal waves have been studied in Bute and Knight Inlets, and measurements of current profiles from the surface to 1000 feet have been made. Internal waves have been studied in the inlets, and surge currents as great as 1 knot are found to occur in the deep waters, hitherto considered as stagnant or nearly so. A study of ionic ratios in the brackish waters of several estuaries has shown that the magnesium ion content was greater and the potassium ion content less in these regions than in normally saline waters. The increased magnesium ion content is attributed to the fresh water, while the lessened potassium ion content is probably due to the cation-exchange effect of silt. The alkalinity of these waters was high and this property might be useful in tracing waters from an individual river.

Sea Ice Research in Canada

The construction of the Distant Early Warning Line involving both Canada and the United States required a very large sea lift. This sea lift, as well as the re-supply of various northern Canadian posts, placed emphasis on the need for sea ice reporting and forecasting programs. Further south, in the Ungava Bay, Hudson Bay, and Hudson Strait areas, problems of summer navigation have arisen in connection with the increased shipping through Port Churchill, and the shipping of iron ore from the newly found deposits of northern Quebec and Labrador. The development of the St. Lawrence Deep Sea Waterway and the ever increasing industrialization around the shores of the Gulf of St. Lawrence have brought about an interest in the possibility of lengthening the navigation season in the Gulf and River St. Lawrence.

The Defence Research Board, through its Geophysics Section, has made a study of the problems involved, and put forward the minimum national requirements. To supply the information required for military and commercial organizations, the minimum data required are:

(a) date of onset of ice in ports and bays,
(b) thickness, distribution, and movement of floating ice,

(c) method and rate of growth and degeneration of ice in ports, bays, and seas, and
(d) reasonable forecasts for the above.

As considered this will require two organizations, the operational group, and the research group. The function of the operational group is to collect and disseminate the information in such a manner that it will assist in obtaining the maximum period of safe operation of commercial shipping in the St. Lawrence in the winter, and in northern Canada in the summer. The function of the research group is to carry forward fundamental studies on the climatic and oceanographic factors that affect the growth, distribution, and degeneration of sea ice.

In 1955, the Defence Research Board initiated a sea ice research program at McGill University. Part of this program is directed toward a study of the physical properties of the sea ice. Field studies have also been initiated by the Meteorological Service and by the Atlantic Oceanographic Group of the Fisheries Research Board. Other government agencies have been active in other aspects of the ice problem, and it is hoped that shortly these will be co-ordinated under a working group of the Joint Committee on Oceanography.

The University of British Columbia Institute of Oceanography

The prime function of the Institute of Oceanography at the University of British Columbia is to provide instruction at the graduate level in the field of oceanography. The instruction includes the presentation of lecture courses in biological, chemical, geological, and physical oceanography, and also the organization of research programs for the students to give them training in field and laboratory procedures and in reporting their work.

The research program of the Institute is at present centered on the inlets and coastal waters of British Columbia. The basic study of the water characteristics of the fjord-like inlets of the British Columbia coast has been carried out during the summer seasons, and the following projects have been furthered:

(a) correlations between benthonic organisms and water properties and circulation,
(b) estuarial and tidal components of flow in deep inlets,
(c) problems of fluid turbulence,
(d) lateral and vertical mixing,
(e) internal waves,
(f) processes of silt deposition,
(g) bottom topography and sediments, and
(h) ionic ratios.

The Canadian Hydrographic Service

The Hydrographic Service carries out an intensive survey and charting program in Canadian waters, where its chief responsibility is concerned with navigational problems. As one of the organizations co-operating under the Joint Committee on Oceanography, the sur-

vey fleet has carried out a regular program of collecting oceanogr phic data while en route to and from the various survey ground The areas so covered include the various straits and passages alor the British Columbia coast, the Gulf of St. Lawrence, the south coa of Nova Scotia and Newfoundland, the coast of Labrador, Hudsc Strait and Ungava Bay. The Hydrographic Service was also involve in difficult charting programs relating to the DEW Line sea li in the far North. The new and modern survey ship *Baffin* is beir readied in 1957 for her first survey work in the northern region

Under the Hydrographic Service, the Tides and Currents Surve has been reorganized into the Tidal and Inland Water Section. Tid current and wave surveys have been carried out in several are where detailed information has been required for harbour installa tions, causeway construction, and tidal power projects. The princip harmonic constituents of the tide at some seventy ports in easter and northern waters have recently been analysed. Cotidal char have been prepared from some of these data showing the propaga tion of the diurnal and semi-diurnal oscillations from the ocea into and around the Gulf of St. Lawrence.

Naval Research Laboratories

The Defence Research Board maintains the Naval Researc Establishment at Dartmouth, N.S., and the Pacific Naval Laborator at Esquimalt, B.C. These naval laboratories co-operate with th Oceanographic Groups of the Fisheries Research Board in furtherin a general oceanographic program in coastal waters, wherein studie are made of the physical and chemical characteristics, the circulatio pattern, and the nature and configuration of the sea floor. Th Pacific Naval Laboratory has been especially interested in problem of turbulence and in the thermal microstructure in the sea. To ai in these studies, equipment has been developed to measure rapidl the temperature of the water to 0.001°C. Of special interest to th Naval Research Establishment are the problems of sound transmis sion in the sea.

Physical Limnology

The Great Lakes, comprising Lakes Ontario, Erie, Huron Superior, and Michigan, constitute large inland fresh water sea and a study of the physical and chemical characteristics of thei waters properly falls under the subject of physical and chemica limnology. These lakes vary in size from Lake Ontario, the smalles with a length of approximately 150 miles and a width of 50 mile to Lake Superior with a length of approximately 400 miles and maximum width of about 150 miles. In depth these lakes vary fron the shallow Lake Erie of depth not greater than 60 metres, to th deep Lake Superior with depths as great as 400 metres. Surrounde in part by the ever-expanding great industrial areas of Canad and the United States, it is not difficult to appreciate that grea changes have occurred in certain environmental factors of thes

waters over the past fifty years. So, too, have great changes occurred in the fisheries.

The developing situation finally resulted in 1955 in the establishment by the United States and Canada of a Great Lakes Fishery Commission, which has the responsibility of making a study of the various fishery problems of these lakes. This will involve limnological studies which will introduce the equipment and methods developed for physical and chemical studies of ocean waters.

Interest in the contrasting characteristics of the various lakes will gradually evolve. In the shallower lakes, the waters are readily overturned by wind action and/or seasonal chilling, while the deeper lakes have either a permanent thermocline, or at least a minimum bottom temperature of approximately 4°C. Differences in physical characteristics will prevail due to the varied alignment of lakes with prevailing winds, and contrasts in chemical constituents vary with geological structures and the degree and kind of pollution. There are contrasts in the circulation system, the height, length and frequency of waves, the magnitude and frequency of seiches, the amount and kind of sedimentation, and the general vertical and horizontal distribution of physical and chemical characteristics such as temperature, dissolved oxygen, nutrient materials, and pollutents.

Oceanographic Symposia

One means adopted to develop the scientific aspects of the subject of oceanography in Canada has been the holding of oceanographic sessions and symposia. This has been the means employed chiefly by the Committee on Oceanography of the Royal Society of Canada. The Nova Scotia Research Foundation organizes conferences as a means of developing an interest in various scientific problems of more local interest. Over the period reported upon, two oceanographic sessions and one symposium have been held under the auspices of the Royal Society and one conference on oceanography has been held under the auspices of the Nova Scotia Research Foundation. These were as follow:

1954. An oceanographic session of the Royal Society on Hudson Bay, with papers relating to climate, ice distribution, physical oceanography, and the production of life.
A conference on oceanography under the joint auspices of the Nova Scotia Research Foundation and the Nova Scotia Department of Mines, with the subject matter covering all aspects of oceanography.

1955. An oceanographic session under the auspices of the Royal Society with papers on physical, biological and meteorological problems.

1956. A symposium under the auspices of the Royal Society, entitled: "The Ocean Floors around Canada".

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EDMOND CLOUTIER, C.M.G., O.A., D.S.P.
QUEEN'S PRINTER AND CONTROLLER OF STATIONERY
OTTAWA, 1957.

erh. internat. Ver. Limnol. | XIII | 84—100 | Stuttgart, Februar 1958

Production, reproduction and yield

W. E. Ricker

Editor, Fisheries Research Board of Canada

With 11 figures in the text

FRB No. 484

The objective of a complete description of productivity in a body of wat an ambitious one, though not necessarily an impossible one. In this, as in o endeavours, man should aim high; and I wish to express my admiration for t investigators who have delved and are still delving deeply into the various asp of primary aquatic production and the transformation of material and en from one organism to another. I see many of these investigators in the audi before me.

To-night, however, I will consider only a restricted aspect of productivity. stage at which a usable product is available, and what man can do to make use of this product. At the present time, and for many years ahead, in n a t u r a l waters man's principal opportunity for action will be manipulatio the population of the species he uses, rather than manipulation of its food o primary production of the water.

In the case of fish populations, the usable product usually means fish w exceed some minimum desirable size. If a stock is n o t being used by ma presents an equilibrium situation like the upper panel of fig. 1. The stock t to increase as its members grow, and because new recruits are added to i decreases because of so-called "natural" deaths — from predation, disea senility. For the moment we will pass over the problems of disturbance of equilibrium, and note only that typically the level of stock abundance is not pletely fixed, but fluctuates up and down in response to environmental varia or because of rhythms of internal origin.

When man starts to use the population, he inserts a new item on the drawal side, which is his catch or yield — as shown in the lower panel of f The new removals are something extra taken away from a system which already in balance. At first sight it might seem that by this tipping of the s man should soon exhaust the stock and bring it close to extinction. This happen, of course; but apparently it has not happened very often. The testi

umerable reasonably stable fisheries is that a variety of new equilibria can t up, in which a part of the stock is removed by man each year — sometimes a large part.

ow if the new item — yield — is added to the system, it can come to a new ibrium only if there are adjustments in one or more of the other three items. is, either growth rate increases, or recruitment increases, or natural mortality ases. What is the evidence concerning changes in each of these?

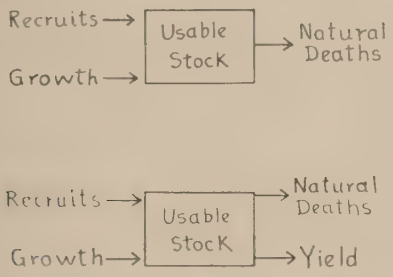

Fig. 1. Above: Flow of matter through a fish stock when there is no fishing. Below: Flow of matter through a fish stock when there is exploitation by man.

Natural mortality

ur usable stock, in the days before fishing, was removed from the system by the causes we classify as "natural" — that is, disease, predation, senility, unfavorable physical conditions. Since such an unused stock does not conusly increase, a lot of fish must die every year from these causes. In general, ave almost no quantitative knowledge of the exact causes of natural death at ssive ages. For most stocks our information goes little beyond some evidence predation is more important for younger fish, that senility and possibly disease nore important for older fish, while an unfavorable environment may affect

What is the effect of fishing on natural mortality? Firstly, fishing competes natural mortality for the fish available, so that the actual number of natural s in a given year is automatically reduced. But this does not necessarily t the rate of natural mortality at a given age, and there are a few cases e it is known that natural mortality rate has been little if at all affected by stablishment of a fishery (e. g., Tester 1955). However, for the usable k as a whole the rate may decrease, because often a fishery cumulatively es the relative number of older fish, and these tend to have a greater al mortality rate than do the younger members of the usable stock. On the hand, if the total size of the usable stock is reduced by the fishery, the survimay be less subject to attack by parasites, while their (possibly) better nutrimight postpone old age.

In practice, computations of expected yield are commonly made on the b that rate of natural mortality at a given age does not change under different le of exploitation.

Growth rate

For centuries it has been known by fish-culturists that the growth of fis eating natural foods, in a pond, depends above all upon the density of the st The fewer fry stocked, the larger are the fingerlings at the end of the seaso whether you are raising *Cyprinus, Lepomis, Salmo* or *Tilapia.* Another pertin observation is that, in nature, when successive yearclasses of a species vary gre in abundance, often the large broods grow more slowly than the small one least during their first year or two of life.

In view of this, we might expect increased growth to follow the reductio population which accompanies exploitation. And as a matter of fact, some stri increases in growth rate h a v e been observed soon after a fishery starts, or a it becomes intensive. One of the earliest examples known to me concerns Da (1919) studies on trout in mountain tarns. By netting a stock fairly heavily increased the size of age V individuals, for example, from 57 grams in 191 94 grams in 1913 and up to 127 grams by 1916. Another north European exam concerns the flatfishes of the Kattegat and western Baltic Seas. The original l stocks of plaice *(Pleuronectes platessa),* flounder *(P. flesus)* and dab *(Lima limanda)* in this area consisted of old slow-growing individuals. Already by 1 the valuable plaice had been intensively fished and greatly thinned out: at same time its growth rate increased enormously (Petersen 1922). The less v able flounders and the dabs were reduced later, and over the period 1919—1 they too reacted sharply (Molander 1938). In the Baltic, for example, floun of age V in 1937 were much larger than in 1919 (fig. 2); in fact they were la than even those of age VII in 1919. At the same time, the modal age in the c decreased from age IV or V in 1919—1925 to age II in 1935—1937. Much same sequence occurred in the Gulf of Peter the Great when the flatfishes t were first exploited during the 1930's (Moiseev 1946).

In America, similarly striking changes in growth were observed following in sification of fishing for *Coregonus* in certain Alberta lakes (Miller 1952, 1 For example, in Lesser Slave Lake (1190 square kilometers) unrestricted fis for tullibee, *Coregonus artedii,* was followed by greatly increased growth rate earlier maturity: in 1941 the catch consisted mainly of fish of ages V—VII 1947 and subsequently, 80 to 90 per cent of fish taken have been of ag Similarly, in Pigeon Lake (104 square kilometers) fishing for *Coregonus clu formis* was suddenly intensified, stocks declined for that reason a n d becau 2 or 3 years of poor spawning conditions, and "condition" of the fish incre Later fishing was relaxed, the stock increased again, and growth declined t former level. During this cycle the average weight of an age III whitefish incre from 0.6 kg to 1.0 kg then decreased to 0.7 kg.

he number of pertinent examples could be greatly increased by considering
:es in growth due to density changes caused by factors other than fishing
stricto. For example, BECKMAN (1941) observed a marked increase in growth
nbloplites rupestris in a lake of 13 hectares, after its fish population of all
s had been reduced to about half by poisoning. More surprising, possibly,
fact that in a lake as large as Lake Michigan the pelagic fish *Osmerus mordax*
2—2.5 times as fast, during a time of very low abundance, as it did when
s numerous (VAN OOSTEN 1947).

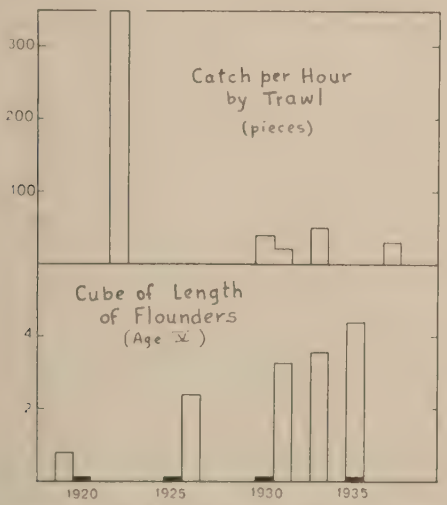

Fig. 2. Comparison of fishing success for *Pleuronectes flesus* in the western Baltic Sea (above) with the average size of the fish at age V, over the period 1919—1937. (Data from MOLANDER 1938.)

owever, there are also examples where an intensive fishery has made little
change in rate of growth of the stock. In general, of course, we should not
t marked changes in growth rate to follow fishing, if the species in question
ly a minor component of its habitat. However, even large stocks may be in
ame position. For example, stocks of *Clupea pallasi* in southern British
mbia were fished at a level of about 20 000 metric tons per year during 1910
20, but in recent years have averaged three times that (TAYLOR 1955). Samples
in most years from 1915 to the present indicate that the average length
4 growing seasons, when the fish are first fully recruited to the fishery, has
d no more than a few millimeters — which is within the limits of accuracy
ie sampling procedure (fig. 3). This absence of any important effect on
th rate is not because the rate of exploitation is light. This fishery is con-
d by purse-seining dense schools in shallow water, and is estimated to
ve 55 per cent of the maturing stock each year (TESTER 1955). The mean age

of the fish in these schools is to-day about a year less than when the catch
small. We must conclude that either herring are not labile in respect to gro
rate or, more likely, that even these extensive commercial operations have
changed the total plankton-consuming community of the sea sufficiently to m
any important change in the availability of food to individual fish. Similar c
ditions have been reported by Dementeva (1953) for a number of marine fis

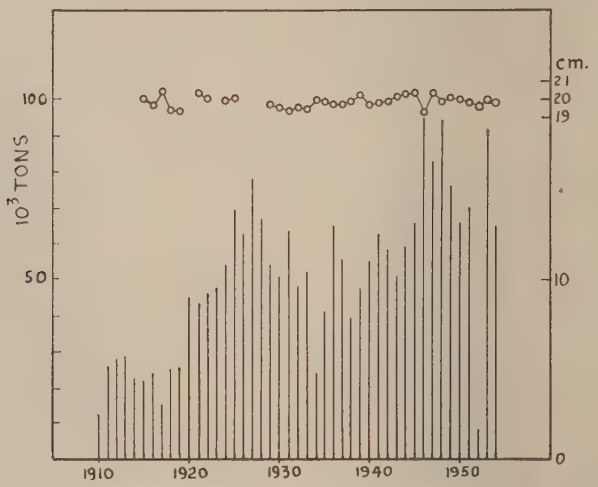

Fig. 3. Catch of herring *(Clupea pallasi)* in southwestern British Columbia (histograms, below), compared to the observed average length of age III individuals (4 growing seasons completed) in the "Lower East Coast" section of this fishery. (Data from Taylor 1955 and MS.)

Recruitment

The usable stock normally consists mainly of adult fish. If some of t
adults are removed, it seems logical to expect less reproduction and fewer recr
Obviously there will be less reproduction, in the sense of fewer eggs laid.
what interests us is the net reproduction to usable size, which is often c
recruitment.

A useful concept, in considering this matter, is the replacement le
of stock: the size of adult stock which, in the absence of fishing, just reprod
its own numbers and weight, on the average. In other words, it is the lev
which parental reproductive potential equals progeny reproductive potenti
these are measured in comparable units — for example, the number of eggs
duced by a given year's mature stock, compared with the number of eggs v
its progeny will eventually produce.

To maintain this average replacement level in the face of fluctuations ca
by environmental variability, it is necessary only that the rate of recruit
should decrease when population increases beyond the replacement level (fig.

is, when the number of recruits fails to increase as rapidly as does the parent which produced them, the tendency is for abundance to be swung back to eplacement value.

lowever, it appears that increasing the adult stock beyond a certain point may actually reduce absolute recruitment (fig. 4B). For example, it is a matter mmon observation, in pond culture of centrarchid fishes, that far more young roduced in a pond containing few adult spawners, than in a pond containing 1/.

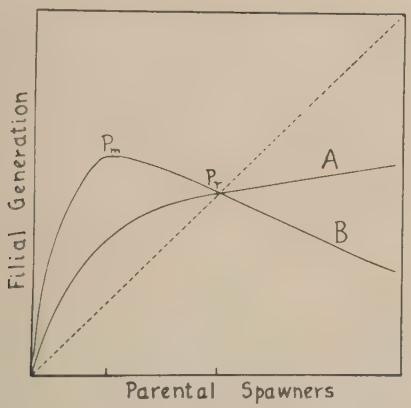

Fig. 4. A. A reproduction curve in which the amount of progeny continually increases with increase in adult stock density. B. A reproduction curve having a maximum of reproduction at an intermediate density of spawners. P_r: replacement reproduction; P_m: maximum reproduction.

n nature, it is usually not so easy to learn what each year's absolute level of oduction may be, and even less easy to arrange for the adult stock to vary ely in abundance from year to year so as to explore the full range of possible ities. Nevertheless, a number of examples are available which show that r natural conditions, too, the absolute number of recruits does frequently ease when population increases beyond some optimum level (Ricker 1954).

When I first considered the variety of forms of reproduction curve which turned n even a very limited number of actual observations, it seemed impossible they would have much in common. Closer consideration showed that a ber of them, though not all, might be described by a simple expression which be deduced from simple theoretical considerations (Ricker 1954 and MS). cruitment, Z, and the reproductive stock, W, be both expressed as a fraction e replacement level of stock (P_r), then the formula below describes these tions:

$$Z = We^{a(1-W)} \qquad (1)$$

parameter a is equal to $P_r - P_m$, where P_m is the level of parental stock required maximum reproduction (cf. fig. 4).

Fig. 5 shows five curves derived from (1). Although very different in fo these curves differ solely as regards the numerical magnitude of a.

A surprising feature of stock-recruitment relationships, first noticed by Mo (1950), is that they tend to perpetuate fluctuations in abundance provided absolute level of recruitment begins to decrease (with increase in stock) be

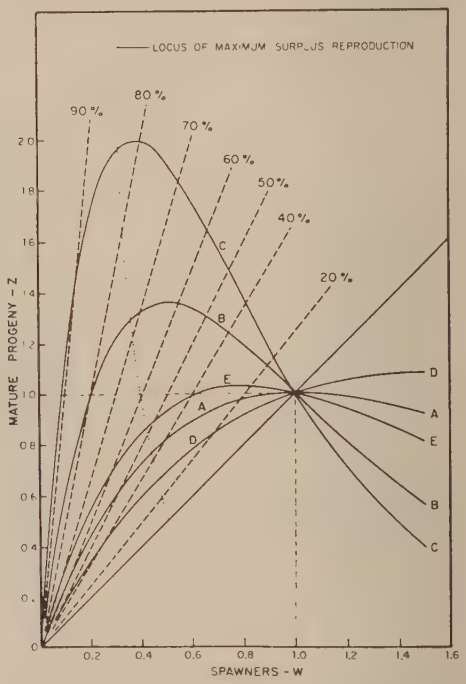

Fig. 5. **Five reproduction curves computed from the relationship $Z = We^{a(1-W)}$.**

the replacement level is reached (fig. 4 B). This is true regardless of what exact stock-recruitment relationship may be. If the decline in recruitment is r enough, the stock is inherently unstable and successive broods will vary in num indefinitely, quite apart from any environmental variability. If the stock has one age at maturity, the abundance of successive generations may trace a c plex cycle. If there is a mixture of ages at maturity, the result can be a f regular cycle of abundance whose period is twice the mean length of a genera (fig. 6). However the period is easily disturbed by year-to-year variation reproductive success caused by environmental factors, while removal of pa the stock by a fishery tends to reduce their amplitude (Ricker 1954).

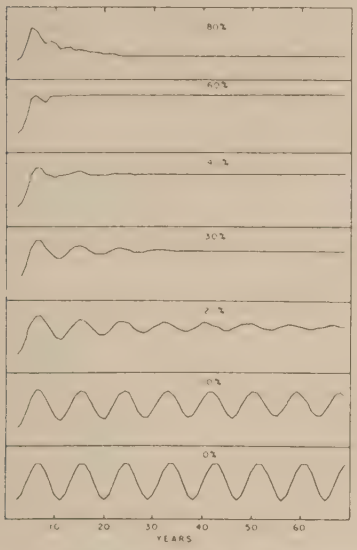

Fig. 6. Models of year-to-year fluctuations in stock when the reproduction curve is steep, and when the fishery removes the various percentages indicated. The graphs show the size of the stock before fishing each year. All graphs are drawn to the same scale, and all start from a state of no fishing, at the low point of the cycle. (From Ricker 1954, fig. 17.)

Qualitative and temporary changes resulting from fishing

uvenation of the stock. The principal qualitative change in the le stock, due to fishing, is the younger age structure which it acquires (Hunts- 1918; Baranov 1918; Thompson and Bell 1934). Any removal by the ry increases total mortality rate. This effect is cumulative from year to year, at in a stock fished at many ages even a light fishery can produce a very rtant change in age structure (fig. 7).

emporary effects of fishing. Just after a fishery starts, the new structure which it determines does not come into existence all at once: rather, tends progressively through the population as more and more year-classes the full effect of the new rate. During this time catches are large because of "fishing-up of the accumulated stock", as it is usually called. These catches commonly much larger than what the same amount of fishing effort will uce after this initial fishing-up is completed (fig. 7).

his phenomenon is important in a number of ways. For one thing, it makes fficult to determine a level of maximum sustained yield (or other desirable l) by a policy of experimental regulation. For another, if a desirable level been determined which requires less fishing than what would give fishermen

a marginal return (in the economic sense), then there is constant pressur exceed this level of fishing because of the lush temporary profits of the fishin stage. Conversely, if fishing already exceeds the level which gives maxi yearly yield (as it is shown, for example, in the top panel of fig. 7), a return lower level of fishing and higher yield requires temporary sacrifices from fishermen, which are sure to be painful and unpopular.

Lag in the expression of density-dependent effects least two factors make for a delay in the response of a stock to a given lev fishing effort.

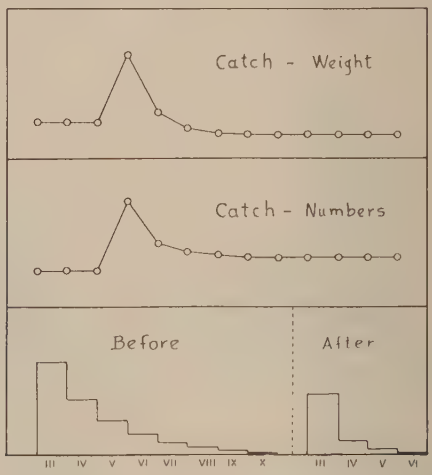

Fig. 7. Upper two panels: Sequence of annual catches in a stock when instantaneous rate of fishing is increased from 0.3 to 1.3 in the fourth year and then held steady (natural mortality rate, growth rate at a given age, and absolute annual recruitment are all held constant). Lower panel: Age structure of the population when stabilized at the two levels of mortality — before the increase in rate of fishing (at left) and after the increase (at right).

(a) If rate of growth responds to a change in stock density, the beginnin the response will presumably be immediate, and can be detected immediatel cases where year-by-year growth increments can be read from scales, etc. the other hand, the previous growth history of a fish may affect its current gro and even if not, the size of a fish at a given age is the cumulative result of al earlier growth. Hence the complete equilibration of growth to a given s density requires as many years as the age of the oldest age-group which oc in appreciable numbers.

Complications can occur, of course; for example, the fish's food supply m react to an initial stock decrease by greater production, which would have se dary effects upon growth, etc. (Burkenroad 1951). However such possibil seem to be beyond the scope of observation to date.

) If recruitment varies in response to stock density, it tends to lag behind onditions which determine it. I have considered that, usually, the relative of recruitment is determined in the first year of the fish's life, and that pensatory" mortality is not important thereafter. If so, a given parental of stock abundance has its greatest effect on the actual stock only after an al of time equal to the median age of the fish in the fishery (adjusted for it). It is this lag which makes possible the sustained fluctuations in abundance rated in fig. 6.

ter-specific reactions. I must mention briefly, too, the possi- of reactions of abundance between species. Several fairly distinct ideas are ved. On the one hand, there may be natural interactions between two es which keep the populations of both in continuous fluctuation. Or two peting species may be best adapted to somewhat different climatic conditions, as the weather varies, one or the other gains the upper hand. Finally, man disturb a balance by taking some species and leaving others, thus favoring which are less desirable or less catchable. It was some observations made ir Chairman, Professor D'Ancona, upon fish stocks of the Adriatic Sea some ars ago that stimulated his compatriot, Dr. Vito Volterra, to make those ematical analyses of possible effects of interspecific competition and pre- n which have had such wide attention. However this is a very difficult sub- on which to obtain data that are quantitative and reproducible, without being implified. In waters such as Lake Erie, in North America, fishing has favored species over others. Where formerly *Coregonus* was the dominant genus in ake, to-day it is *Stizostedion (Lucioperca)* and *Perca;* while *Acipenser* has ne very scarce and *Esox masquinongy* has disappeared. Yet it seems likely altered environmental conditions may also have contributed to some or all ese changes, and the exact degree of their influence can scarcely be dis- ed. Hile (1954) has concluded that in the Great Lakes, interspecific inter- ns and environmental variability are so important that no attempt can yet ade to compute optimum levels of exploitation for individual species.

Calculations of equilibrium yield

Considering the simpler situations where, for one reason or another, inter- n between species can be disregarded, it is desirable to be able to compute atch expected under specified conditions of exploitation. For example, we be interested in maximum poundage, or greatest financial return, or most f desirable sizes, etc. For estimating any such level of equilibrium yield of ck, the concurrent variation in growth, recruitment and natural mortality, kind and amount of fishing, should all be taken into account. No such com- analysis of a fish population has yet been published, mainly because the

data are not yet available. However calculations of equilibrium yield have b proposed using various kinds of simplifying assumptions, of which we will sider four.

(1) Firstly, calculations have been made which assume that change in p lation size does not change the rate of growth or the rate of natural mortalit in the first instance by Baranov (1918), later by Ricker (1945), most recentl Beverton and Holt (see Beverton 1953). That is, a calculation of the yield unit weight of recruits is made for the different conditions postul

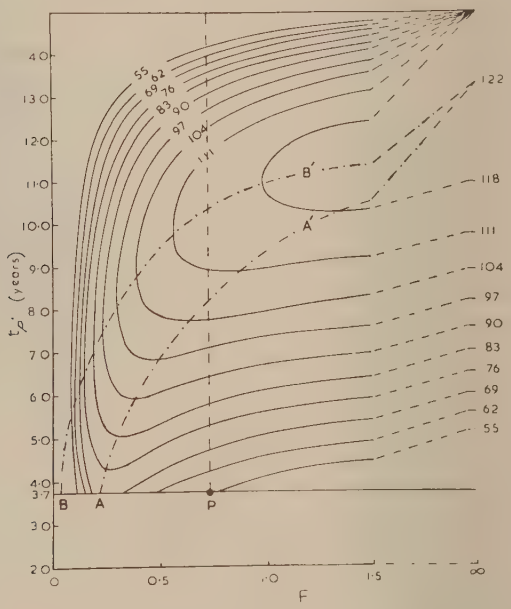

Fig. 8. Yield contours (isopleths) for North Sea plaice, related to variation in instantaneous rate of fishing (abscissa) and average age of first removal by the fishing gear (ordinate), when rate of growth and absolute recruitment are constant. The scale of yields, at right, is in thousands of tons. (After Beverton 1953, fig. 2.)

Usually equilibrium yields are computed for a series of combinations of rat fishing and size at recruitment: that is, the desirability of excluding some por of the smaller usable fish from the fishery is examined. Beverton and Holt d loped their calculations to the stage of calculating a yield surface whose cont are the lines of equal catch (fig. 8). Kesteven and Holt (1955) carry this furt and define the region within which neither catch nor fishing success will be than under existing conditions (fig. 9) — always assuming that rate of growth absolute recruitment are steady.

Secondly, and in contrast to the above, Nikolsky (1953) considers situa-
n which rate of growth does vary; in fact he takes the extreme position that
n rate is the best indicator of the productive "condition" of a stock. Maxi-
ield, he says, should be obtained when the fish in a stock are growing at
the most rapid rate possible u n d e r t h e e x i s t i n g p h y s i c a l c o n -
n s. To learn whether maximum yield is being obtained, we should, on
ew, experimentally determine the maximum growth rate by feeding some

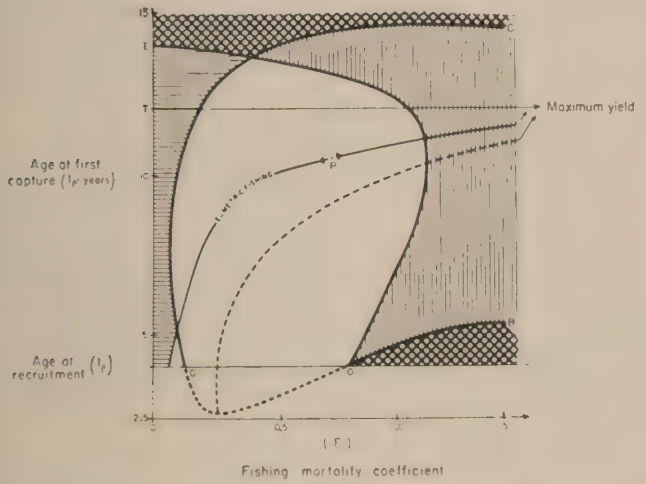

Fig. 9. Delimitation of regions of favorable and unfavorable fishing intensity by Kesteven and Holt (1955, fig. 1), for the North Sea plaice fishery shown in fig. 8. The point 0 represents the combination of instantaneous rate of fishing (horizontal axis) and average age at first capture (vertical axis) which now exists in the fishery. A change to any other position in the unshaded area above the line t_p is calculated to increase both the sustained yield and fishing success (catch per unit of effort). A combination of fishing effort and selectivity in the horizontally shaded area would decrease catch but increase fishing success; in the vertically-shaded area catch would increase but success would decrease; in cross-hatched areas both catch and success would decrease. The "eumetric fishing" curve indicates the best minimum age of first capture for each rate of fishing.

l they will eat under conditions otherwise as natural as possible. If they substantially more than the wild fish, then the latter should be fished more y, until their stock is reduced and growth increases.

ie reasoning behind this argument is apparently the known fact that (up to it at least) the larger a fish's daily ration, the larger is the fraction of that which is transformed into flesh, and the smaller the fraction used for enance metabolism (Ivlev 1945). Furthermore, the larger the rate of exploi-. the more young fish there are in a stock, relative to the old fish. Young fish

convert into usable flesh a larger fraction of their food than do old fish (fo given ration per unit body weight), partly because the older fish must div substantial portion of their food to the production of eggs or sperm. Hence younger stock there is a net gain in production from this cause.

This approach has apparently not yet been applied in a quantitative ma to any fishery. Indeed its basic proposition, that maximum usable productio a species is achieved at the stock density where rate of growth first reach maximum, must first be tested — as could easily be done with a series of populations. Nikolsky mentions several qualifications, chief among which (1) that reproduction must be maintained, or even increased, at the reduced l of stock, and (2) that no undesirable species should appropriate the "liber food supply and multiply its own numbers.

(3) There are some important fish populations for which a sufficiently description of equilibrium yields can be had by considering changes in rec ment alone. Above all this is true of the Pacific salmons *(Oncorhynchus)* bec (a) they mature only once and are available to the fishery for the most part as they are approaching maturity, and (b) over many years they have exhi no significant variation in growth rate that can be related to stock density on different parts of the North American coast very large changes in density been observed). For these fish, it is relatively simple to determine the siz each year's recruitment, and to relate it to the parent stock. In some stocks the age at maturity is fixed.

Certain other populations, particularly among those whose growth rate i very variable, may also be treated on the basis that recruitment is effectively only contributor to variations in stock size.

(4) Observed relation of equilibrium yield to abunda For some stocks it may prove that the several individual effects of exploit will always be too complex to be measured separately and then recombined. such, attempts have been made to work out a direct relationship between and abundance (or rate of fishing). The difficulty is, of course, that it takes years for a stock to come into equilibrium with a fishery, so we can expect to few points on any graph of sustained yield against fishing effort.

Baranov (1926 etc.) attempted a calculation of this type, starting Petersen's concept of a constant food production, but his argument s unnecessarily involved. Graham (1935) tackled the problem for North Sea de sal fishes as a whole. He had two equilibrium points on a graph of yield ag size of stock (as represented by catch per unit effort), one for the years b 1914 and one for 1925—1933; he also had an approximation to the size o stock under conditions of no fishing, which was deduced from the increa stock density after World War I. From these he was able to relate equilib yield to catch/effort, aided by the assumption that this relationship is para (fig. 10).

lecently Schaefer (1954, 1955) has ingeniously obtained a lot of points for relationship, in a few fisheries, by computing each year's "surplus production" natural increase" (catch plus any increase in stock size or less any decrease), plotting it against catch per unit effort or actual population size. Alternaly, catch can be plotted against fishing effort to illustrate the same relationship

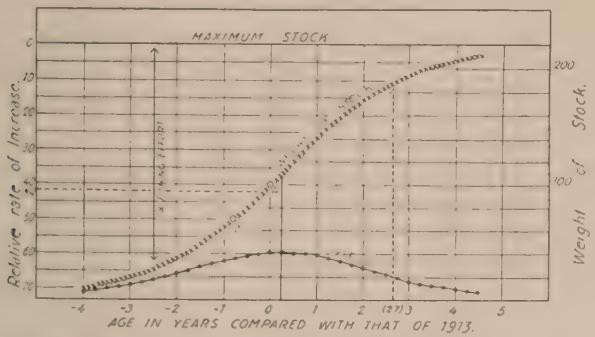

Fig. 10. Stock and yield relationships postulated by Graham (1935, fig. 1) for North Sea demersal fishes. The solid line shows the sustained yield corresponding to the level of stock indicated on the S-shaped curve (crosses) directly above. The fishing effort required to take the yield in question varies as the distance from the crosses-line to the top of the graph.

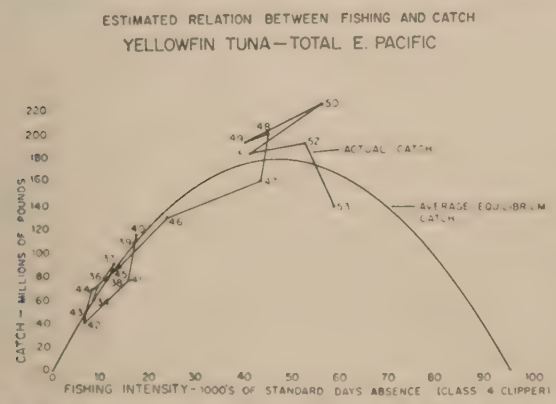
ESTIMATED RELATION BETWEEN FISHING AND CATCH
YELLOWFIN TUNA—TOTAL E. PACIFIC
ACTUAL CATCH
AVERAGE EQUILIBRIUM CATCH
CATCH - MILLIONS OF POUNDS
FISHING INTENSITY - 1000'S OF STANDARD DAYS ABSENCE (CLASS 4 CLIPPER)

Fig. 11. Estimated relation between fishing effort (intensity) and catch of yellow fin tuna in the eastern Pacific Ocean. (After Schaefer 1955, fig. 7.)

1). This procedure is effective if the influence of stock size on surplus pron is immediate; but if there is any important lag in this influence (for readiscussed earlier), the relationship found can be quite misleading. Apart that, in the actual examples available the scatter of the points is such that is no very clear indication of the shape of the stock-yield graph, and of the

position of its maximum in particular; in order to compute a maximum, SCHAEFE like GRAHAM, has had to resort to the assumption that the relationship is pa bolic. However if the fishing effort for yellowfin tuna were to increase subst tially beyond the 1953 level (fig. 11), a test of the provisional relationship will possible.

Environmental variability

Effects of environment upon the size of fish stocks and their yield are w known. On a long-term scale, they can be blamed for such phenomena as t fluctuations in Norwegian herring or the abundance of cod off Greenland; a we noticed earlier that they may contribute to the shifts in species compositi of the Great Lakes catches. On a year-to-year basis, varying physical conditio can cause variations in recruitment which may be considerably greater than tho associated with observed fluctuations in size of the parental stock. If the effe of environmental influences can be quantitatively evaluated, predictions of yi become more precise; while by removing such effects from the data, the influen of other factors can be discerned more clearly in the residuals. Analyses of t sort have been done by HENRY (1953) and by NEAVE and WICKETT (1953), wh I have seen a more elaborate treatment of Karluk sockeye salmon reproduct and yield by G. A. ROUNSEFELL (unpublished).

In the future we may expect to see more complex analyses performed, w greater diversity in both the physical and the biological variables. The new el tronic computers provide a physical basis for this approach, but the collection a collation of appropriate data is as yet in its infancy.

Conclusions

Means for measuring and predicting effects of fishing upon the yield of stocks are as yet imprecise and insufficiently tested, but are nevertheless pro sing. A variety of approaches to the question are available, suited to differ types of stocks. The principal obstacles to more rapid progress are technical d culties in obtaining the necessary population statistics, and the year-to-year va bility in production caused by a variable environment. However, we can and must continue work in a field which is at once so important and so fascinati

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ABNORMAL APPENDAGES OF THE PACIFIC EDIBLE CRAB, *CANCER MAGISTER* DANA

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Since 1950 six specimens of *Cancer magister* bearing abnormal appendages have been received at the Biological Station. The purpose of this article is to record with brief descriptions these abnormalities. No attempt was made to examine the internal anatomy of the appendages.

A photograph of each appendage is shown in Plate I; each photograph is identified by a letter corresponding to one which appears in the text description below. The photographs were taken by Mr. C. J. Morley.

A. Right cheliped of female, carapace width 127 mm., with small abnormal cheliped arising from the base of the movable dactylus. There is no articulation in the abnormal cheliped. The inside margins of the dactyli are serrated as in normal chelipeds. The crab was caught by the trawler " Norma N " off the Fraser River during 1950.

B. Left cheliped of male, carapace width about 170 mm., with a fixed abnormal cheliped originating at the base of the movable dactylus. The inside margins of the two abnormal dactyli are weakly serrated. At the base of the fixed cheliped is a small rod-like projection. Submitted by Mrs. W. Reader, Victoria, B.C., April, 1952.

C. Right fifth ambulatory leg of male, carapace width 174 mm., with partial splitting of the dactylus. The crab was caught in Shoal Harbour, Vancouver Island, about March 30th, 1954, and submitted by Mrs. W. Reader.

D. Right cheliped of large male, exact size unknown, with abnormal appendage arising from the upper surface of merus. This appendage consists of an immovable basal segment with two small projections arising independently from its distal portion. The longer projection is formed of two articulated segments; the distal end of the second segment is broken, indicating that the segment was formerly longer. The short projection is of one segment, articulated at its base. A wound scar is present on the opposite side of the merus. The crab was caught in Burrard Inlet on July 25th, 1952.

E. Right third maxilliped of male, carapace width 146 mm., with small abnormal cheliped arising from the merus of the exopodite. This cheliped has replaced the palp of the maxilliped which normally arises from the merus. The cheliped is articulated. There is a wound scar on the merus of the exopodite at the base of the cheliped. This crab was caught by the boat " Bob " in Burrard Inlet in 1951.

F. Left cheliped of large male, exact size unknown, with abnormal divergent dactyli arising from the outer edge of the propodus adjacent to the normal movable dactylus. The fixed dactylus (normal) projects inward, so that it does not mesh properly with the movable dactylus. The outer edges of the abnormal appendage are serrated. The crab was caught by the trawler " Frank Winfield " near Clo-oose, Vancouver Island, on April 26th, 1954.

As far as known, abnormal appendages have not been recorded previously for *C. magister*. Records of abnormalities are available for other species of brachyuran crabs. Calman (1913, 1924) described two specimens of the European edible crab, *Cancer pagurus*, with chelæ in place of normal walking legs. A case of duplicity in the chela of *Portunus puber* was described by the same author. Perkins (1925) recorded abnormal appendages of *Carcinus mœnas*.

Plate I. Abnormal appendages of the crab *Cancer magister*.

The writer believes that the present abnormalities have resulted through disorientated regeneration following injury. In two of the cases described here, wound scars are visible. The authors cited above were of the opinion that most abnormal appendages were the result of regeneration after injury. Perkins (op. cit.) found abnormal walking-legs on a female of the species *Carcinus mœnas,* which was parasitized by *Sacculina* sp. In the present specimens of *C. magister,* no parasite was found.

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VICTORIA, B.C.
Printed by Don McDiarmid, Printer to the Queen's Most Excellent Majesty
1957

1,125-657-8406

Reprinted from Archives of Biochemistry and Biophysics, Volume 70, No. 2, August, 1957
Academic Press Inc. *Printed in U.S.A.*

ARCHIVES OF BIOCHEMISTRY AND BIOPHYSICS 70, 477–490 (1957)

Nutrition and Metabolism of Marine Bacteria. V. The Inhibition of Growth of a Marine Bacterium by Amino Acids and the Development of Resistant Strains

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Received January 9, 1957

Introduction

One marine bacterium has been selected from a group whose nutritional requirements have been surveyed (1), and it is being subjected to more detailed study.

The organism, designated B_{16} in this and in previous reports, has simple nutritional requirements, but, although it can oxidize a number of amino acids rapidly and extensively, it fails to grow with several of them as sole source of carbon. The reason for this has been investigated, and the results presented here indicate that the failure of the organism to grow is probably due to inhibition by the compounds concerned. In addition, evidence is presented that strains of the organism can be developed which are resistant to inhibition by certain naturally occurring amino acids.

Materials and Methods

The methods used to carry stock cultures and to measure growth responses have been described (2).

The nonsynthetic medium used consisted of 0.5% yeast extract, 0.8% nutrient broth, 0.1% $(NH_4)_2SO_4$, and 0.02% K_2HPO_4-KH_2PO_4 (pH 6.7) dissolved in artificial sea water.[1]

Synthetic media were prepared by substituting for the nutrient broth and the yeast extract of the nonsynthetic medium any desired carbon source and adding .0011% $FeSO_4$.

[1] Composition of artificial sea water from Lyman and Fleming (3) with slight modifications: NaCl 0.4 *M*, Na_2SO_4 0.0275 *M*, $NaHCO_3$ 2.3 m*M*, KCl 8.9 m*M*, KBr 81 m*M*, $MgCl_2$ 0.052 *M*, $SrCl_2$ 0.15 m*M*, H_3BO_3 0.42 m*M*.

In growth experiments, incubation was continued for at least 21 days where growth failed to appear.

Artificial sea water was used in washing cells. Cells to be used as inocula in growth experiments were washed twice; those to be used in respirometer experiments, three times. Inocula used contained about 0.05 mg. dry weight of cells for each 10 ml. of medium.

Conventional procedures were followed in Warburg respirometer experiments (4). Experimental conditions are described in the tables and figures.

Results

Oxidation of Amino Acids by Washed, Whole Cells

The oxidation of amino acids by washed cells of B_{16} was examined. Cells were grown in two different media, one nonsynthetic containing nutrient broth and yeast extract, the other chemically defined, with succinic acid as sole carbon source. The ability of cells to oxidize the compounds, and the influence of the composition of the growth medium on that ability are shown in Table I.

The very marked decrease in the ability of the cells to oxidize amino acids following growth with succinic acid as sole carbon source suggests that the oxidation of most, if not all, of these compounds by whole cells is under the control of adaptive mechanisms. The data also show that cells grown under suitable conditions have the ability to oxidize many amino acids rapidly and extensively.

Amino Acids as Sources of Carbon and Nitrogen for Growth

The amino acids listed in Table I were tested singly for their ability to support the growth of B_{16} in the synthetic medium. Washed cells grown in the nonsynthetic medium were used as inoculum.

Of the 13 amino acids oxidized extensively by the cells, only five L-alanine, L-serine, L-aspartic acid, L-glutamic acid, and L-proline, supported growth of the organism when serving as sole carbon source. When either L-aspartic acid or L-serine was the carbon source, growth occurred only after an exceptionally long lag period: 10–12 days for L-aspartic acid and 6–7 days for L-serine.

The amino acids were next tested for their ability to serve as nitrogen source in the synthetic medium with succinate as carbon source and with the $(NH_4)_2SO_4$ omitted. Under these conditions all of the amino acids listed in Table I supported growth except DL-α-amino-n-butyric acid, L-hydroxyproline, L-tryptophan, DL-norleucine, and DL-norvaline.

TABLE I

Oxidation of Amino Acids by Washed Cells of B_{16}

Each Warburg vessel contained 7 mg. dry weight of cells, and 133 μmoles sodium phosphate buffer, pH 6.7, in a final volume of 2.8 ml. of artificial sea water. Five μmoles (10 μmoles DL-forms) of substrate, neutralized with NaOH or HCl as required, was added from side arm after 15 min. equilibration in water bath. Temp. 25°C.; gas phase, air; 0.2 ml. 20% KOH in center well.

Substrate	Growth medium[a]		
	Nonsynthetic		Synthetic
	Q_{O_2}[b]	%[c]	Q_{O_2}
L-Alanine	63	64	9
DL-α-Amino-*n*-butyric acid	25	76	0
L-Arginine	13	56	3
L-Aspartic acid[d]	7	55	0
L-Cysteine	10		6
L-Glutamic acid[d]	9	45	2
Glycine	1		0
L-Histidine	2		0
L-Hydroxyproline	1		0
DL-Isoleucine	81	58	6
L-Leucine	36	54	3
L-Lysine	13	33	1
L-Methionine	4		0
DL-Norleucine	8		0
DL-Norvaline	25	52	6
DL-Phenylalanine	9		0
L-Proline[d]	16	60	10
L-Serine	65	74	19
DL-Threonine	37	75	13
L-Tryptophan	1		8
L-Valine	61	56	3

[a] Described in *Materials and Methods*. Na succinate was the carbon source in the synthetic medium.

[b] Q_{O_2} = μl. O_2 uptake/hr./mg. dry weight of cells, calculated on basis of maximum rate observed. Endogenous uptake subtracted (11).

[c] % = per cent of theoretical O_2 uptake for oxidation of 5 μmoles of substrate to CO_2, H_2O, and NH_3.

[d] pH 7.1 buffer replaced pH 6.7 buffer with these substrates.

Inhibition of Growth of B_{16} by Amino Acids

The fact that two readily oxidized compounds, DL-α-amino-*n*-butyric acid and DL-norvaline, not only did not support growth when serving as sole sources of carbon in the medium but also failed to serve as nitrogen sources suggested that these two amino acids might inhibit growth. In

view also of the failure of many other amino acids to serve as carbon sources for growth, and of the limited growth some of them supported when serving as nitrogen source, it was decided to investigate all of them for ability to inhibit growth of B_{16}. Each compound was tested at a concentration of 0.03 *M* (0.06 *M* in the case of DL-forms) under two conditions. In the first condition it was added to the nutrient broth, yeast extract medium; in the second, to the synthetic medium with succinic acid (0.03 *M*) as carbon source and $(NH_4)_2SO_4$ as nitrogen source. Washed cells grown in the nonsynthetic medium served as inoculum. B_{16} "adapts" to growth with succinic acid as sole carbon source in the sense that the lag period is longer when the inoculum is grown in the nonsynthetic medium than when it is grown in the synthetic medium containing succinate.

When added singly to the complex medium, only four of the compounds, DL-α-amino-*n*-butyric acid, L-tryptophan, DL-norleucine, and DL-norvaline, caused significant inhibition of growth in 16 hr.

The influence of the amino acids on the growth of B_{16} in a synthetic medium is shown in Table II. In this experiment less sodium succinate (0.3 mmole/10 ml.) was added to the medium than was required as a carbon source for maximum growth of the organism. Each amino acid was then added to the medium in the same amount (0.3 mmole/10 ml.), and its effect on growth was compared with that of a further addition of 0.3 mmole of succinate. The table records the amount of growth in each culture at the time when the control culture reached one-half maximum growth, the maximum growth attained, and the time required for the maximum to be reached. The amino acids are divided into three groups based on their effects on growth as follows:

Group A. No greater inhibition in the early stages of growth than that caused by the addition of an equal concentration of sodium succinate to the medium, and maximum growth equal to or greater than that produced in the basal medium without any addition.

Group B. Greater inhibition of growth in early stages than that caused by an equal concentration of added sodium succinate. Maximum growth as in group A.

Group C. No growth at all, or growth severely limited.

Of the eight amino acids that could be oxidized by the resting cells yet that failed to serve as sole carbon source for growth, six (in group *B*) produced marked but transitory inhibition of growth, and DL-threonine (in group *C*) almost prevented growth in the presence of succinate. The inhibition in group *B* in general took the form of a considerable lengthening of the lag period. This suggests that whatever the mechanism of

TABLE II

The Influence of Single Amino Acids on the Growth of B_{16} in Synthetic Medium Containing Succinate[a]

Addition to medium	Growth (dry weight)[b] At 21 hr.	At maximum	
	mg.	*mg.*	*hr.*
None	4	8.5	30
Succinate	2.7	11.5	42
Group *A*			
L-Alanine	7.5	15.5	36
L-Aspartic acid	3.5	12.3	46
L-Arginine	2.3	10.2	40
Glycine	3.6	7.3	30
L-Glutamic acid	8.3	12	30
L-Histidine	2.3	8.2	32
L-Hydroxyproline	3.5	8.9	30
L-Phenylalanine	4.4	11.4	40
L-Proline	8.2	14.8	36
Group *B*			
L-Cysteine	0.1	9.6	38
DL-Isoleucine	0	7.8	90
L-Leucine	0	11.5	70
L-Lysine	1	10.2	40
L-Methionine	0.1	7.2	44
DL-Norvaline	0	7.5	65
L-Serine	0	12.5	42
L-Tryptophan	0	7.4	120
L-Valine	1.8	10.2	40
Group *C*			
DL-α-Amino-*n*-butyric acid	0	0	—
DL-Norleucine	0	0	—
DL-Threonine	1	3.3	44

[a] Basal medium was the synthetic medium with 0.3 mmole succinate/10 ml. Additions made at 0.3 mmole (0.6 mmole for DL-forms)/10 ml.

[b] Growth is expressed as mg. dry weight of cells/10 ml. of growth medium.

the inhibition may be, some means of overcoming it is available to the cells, at least in the presence of a suitable carbon source. Only one amino acid which could be oxidized yet failed to serve as carbon source, L-arginine, proved not to be inhibitory in the presence of succinate.

Development of Cultures Capable of Growth with Inhibitory Amino Acids as Sole Source of Carbon

In view of the fact that the inhibition of growth of B_{16} in succinate-containing medium by certain of the amino acids capable of being oxi-

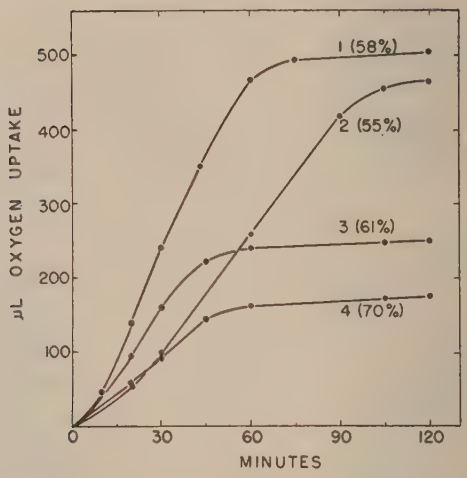

FIG. 1. Oxidation of L-isoleucine (curve 1), L-leucine (curve 2), propionic acid (curve 3), and acetic acid (curve 4), by washed cells of B_{16}. Endogenous oxygen uptake subtracted (11). Experimental conditions described in Table I. The figures in brackets indicate the extent of oxidation of the compounds.

dized by the resting cells appeared to be effective only during the early stages of growth, and that the presence of these amino acids finally increased the total growth of the organism, consideration was given to the possibility of training the cells to grow on certain of these compounds as sole sources of carbon.

L-Leucine and L-isoleucine were selected for use in this portion of the work. Pathways known for the complete oxidation of these two compounds in other organisms pass through intermediates that can be utilized by B_{16} as sole carbon sources for growth (5). These are acetic acid from L-leucine and acetic and propionic acids from L-isoleucine. These compounds are rapidly oxidized (Fig. 1) by whole cells of B_{16} grown under the same conditions as were those used as inoculum in the growth experiments. The extent of oxidation of the amino acids is such that if their oxidation by B_{16} proceeds through the same intermediates as those mentioned above for other organisms, then their oxidation must have proceeded beyond the formation of those intermediates, and it becomes increasingly difficult to understand why growth should fail to occur when the amino acids serve as the sole carbon source. An inhibitory function of the amino acids again suggests itself.

The possibility that at the relatively high concentration of the amino acids in the growth medium, compared to that in the Warburg vessels, their oxidation might be inhibited was considered as a possible reason for the failure of growth to occur with the compounds as sole carbon sources. In the Warburg respirometer, oxidation of both L-leucine and L-isoleucine was found to proceed at the same rate at either the concentration used in the respirometer experiments (Table I) or at the concentration used in the growth media. When the concentration of the amino acids in the growth medium was reduced from 0.03 to 0.007 *M*, growth still failed to appear. These results made it appear unlikely that growth might be brought about by transferring the organism through cultures containing increasing concentrations of the amino acids alone as substrate, and the use of succinate-containing media was investigated.

The organism was grown with sodium succinate, plus L-leucine or L-isoleucine, then transferred to a medium with one of the amino acids as sole carbon source. It was found that although cells transferred from the medium with succinate plus L-leucine to fresh medium of the same composition grew as rapidly as when transferred to medium containing succinate alone, apparently indicating that a mechanism for overcoming the inhibition by L-leucine had been developed, they did not grow when inoculated into medium containing L-leucine alone as carbon source. The same situation was found to exist with L-isoleucine.

It had been observed in separate experiments that a number of amino acids, when added to a synthetic medium containing aspartic acid, shortened the lag period and increased the growth rate over that observed when aspartic acid alone was the carbon source. L-leucine and L-isoleucine were two of the amino acids that behaved in this manner, even though both of these amino acids, as shown previously, produced a pronounced lag when added to a medium containing succinate as sole source of carbon. The apparent contradiction here may be due to the fact that the ability of L-leucine and L-isoleucine to serve as energy sources may obscure their inhibitory effects when L-aspartic acid is the second carbon source. L-Aspartic acid is oxidized slowly, and the lag period is very long when it serves as sole carbon source for growth. However, when cells grown in media containing L-aspartic acid and L-leucine were transferred to media with these amino acids singly, growth occurred first on L-aspartic acid, then, after a lag of about 10 days, on L-leucine (Fig. 2). Subsequently, cells from the latter culture could be carried successfully through serial transfers with L-leucine as sole carbon

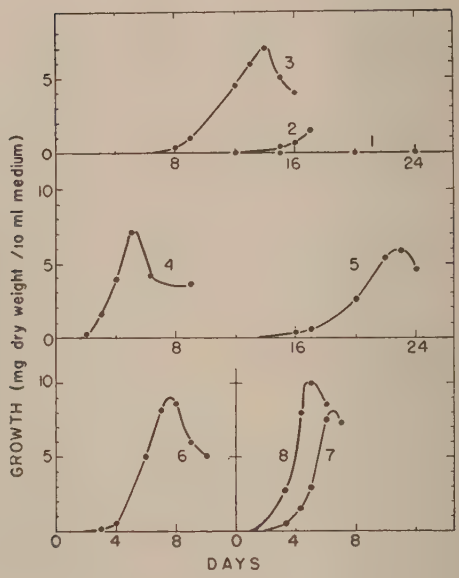

FIG. 2. The development of a culture of B_{16} capable of growing with L-leucine as sole carbon source.

Curves 1, 2, and 3. Growth of B_{16} in synthetic media with L-leucine as sole carbon source (*1*), L-aspartic acid (*2*), and L-aspartic acid plus L-leucine (*3*). The inoculum in each culture consisted of washed cells grown in nonsynthetic medium. With L-leucine no growth occurred in 50 days.

Curves 4 and 5. Growth of B_{16} from the culture of curve 3 above with L-aspartic acid (*4*) and L-leucine (*5*) as sole carbon source.

Curves 6, 7, and 8. Growth of B_{16} from culture of curve 5 above with L-leucine as sole carbon source (*6*) and after two further passages through L-leucine medium (*7*). In curve 8 the growth of the culture in medium with L-leucine and L-isoleucine combined is shown; same inoculum as used in (*7*).

In the growth media, L-aspartic acid was at a concentration of 0.03 *M*; L-leucine and L-isoleucine, 0.02 *M*.

source, the lag being shortened as a result to between 24 and 48 hr. A similar procedure with DL-isoleucine replacing L-leucine produced cultures that could grow in media with either DL- or L-isoleucine as sole carbon source. Thus cultures capable of growth on L-leucine or DL-isoleucine were obtained following growth under conditions where these amino acids initially enhanced growth, but not under conditions where they initially inhibited it.

As inhibition of microbial growth involving interactions among

L-leucine, L-isoleucine, and L-valine are known to occur (6), another possible method of obtaining cultures of B_{16} capable of growing with them as sole carbon sources was investigated. The organism was inoculated into synthetic media containing these three amino acids singly, in pairs, and all together. It grew at a slow rate on all the combinations, relatively good growth being finally attained on L-leucine plus L-isoleucine, and on the three together, but only poor growth on L-valine plus either L-leucine or L-isoleucine. As usual, no growth occurred with the amino acids singly (incubation continued for 50 days). Transfers were made from the cultures in which growth occurred to fresh media containing the single amino acids. Growth now resulted on L-leucine alone with the inoculum grown on L-leucine plus L-isoleucine, and on L-valine with the inoculum grown on L-valine plus L-isoleucine. L-Isoleucine produced a small amount of growth after a very long lag period with the inoculum grown in L-leucine plus L-isoleucine, but this culture failed to grow on the next transfer to L-isoleucine. The cultures now capable of growing on L-leucine and L-valine could be grown successfully in media containing the single amino acids on subsequent serial transfers. None of the transfers from the other combinations grew. In these experiments, equimolar amounts of amino acids had been used in the media (0.2 mmole/10 ml.), and an attempt was next made to see if cultures capable of growing on either L-leucine or L-isoleucine could be developed by growing the organism on either of these amino acids in the presence of low concentrations of the other. When the ratio of the major to minor constituent in the medium was 10:1, cultures able to grow on the major, but not on the minor constituent, were obtained. When the ratio was 100:1, cells failed to grow on either amino acid alone when transferred, although limited growth took place in the initial culture.

Cultures capable of growth on L-leucine or L-isoleucine as the sole source of carbon were still able to grow in a synthetic succinate or aspartate medium or in the nonsynthetic medium. Cells capable of growth on L-leucine, however, did not grow on L-isoleucine as sole carbon source, and vice versa. Growth in other media has not been tested. The ability to grow on leucine or isoleucine was found to persist through 5 serial transfers (more have not been attempted) in either the complex or the succinate medium.

Although a culture capable of growth on L-leucine failed to grow on L-isoleucine, and vice versa, each grew more rapidly on a combination

of these two amino acids than on the single amino acid (see Fig. 2, curves 7 and 8).

The oxidative ability of cultures capable of growth on L-leucine or L-isoleucine was compared with that of cultures lacking this ability grown in the nonsynthetic medium. The derived cultures did not differ greatly from the "parent" culture in their ability to oxidize L-leucine and L-isoleucine.

An Inhibitory Interrelationship between L-Leucine and L-Isoleucine

The fact that cultures incapable of growth on either L-leucine or L-isoleucine as sole carbon source would grow in a medium containing both amino acids suggested that an inhibitory interrelationship existed between them in the growth of organism B_{16}. The ability of various amounts of L-isoleucine to promote growth in a medium containing L-leucine is shown in Fig. 3. The capacity of L-isoleucine to overcome the lag produced by L-leucine in a medium containing succinate is shown in Fig. 4. Although the phenomena illustrated by the two figures are apparently related, one striking difference between them has been observed. Cultures grown in the presence of leucine plus isoleucine alone in suitable proportions will on subculture grow in the presence of either amino acid acting as the sole source of carbon in the medium.

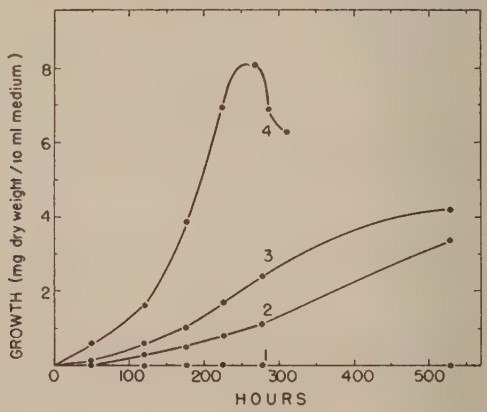

FIG. 3. The growth response of B_{16} to the addition of various amounts of L-isoleucine to a synthetic medium containing L-leucine as carbon source. The synthetic medium contained 0.2 mmole L-leucine/10 ml. with L-isoleucine added as follows: Curve 1, none; curve 2, 0.002 mmole; curve 3, 0.02 mmole; curve 4, 0.2 mmole.

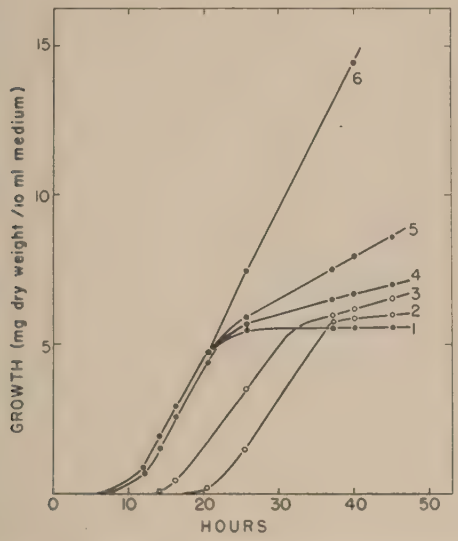

FIG. 4. Inhibition of growth of B_{16} in synthetic succinate medium by L-leucine, nd its reversal by L-isoleucine.

The synthetic medium contained 0.2 mmole succinate/10 ml. with the following dditions: L-leucine; curve 1, none; curves 2–6, 0.2 mmole L-isoleucine; curves 1 nd 2, none; curve 3, 0.2 μmole; curve 4, 2 μmoles; curve 5, 20 μmoles; curve 6, 0.2 mole.

ultures grown in the presence of leucine plus isoleucine in a medium hich in addition contains succinate, however, will *not* on subculture row in a medium containing either amino acid as sole source of car- on.

Discussion

The results presented here indicate that seven of eight amino acids hich could be oxidized extensively by resting cells of organism B_{16} ere somewhat inhibitory to growth when added to a medium containing uccinate. This finding suggests that failure of the organism to grow ith these amino acids as sole carbon source was due to an inhibition y these amino acids which could not be overcome in the absence of a uitable secondary carbon source. Support for such a conclusion was btained from the observation that inhibition of growth by L-leucine in he presence of succinate could be overcome by L-isoleucine and vice ersa, indicating that an amino acid imbalance produced by the presence

of certain amino acids alone in the medium could be primarily responsible for growth failure. Evidence of impairment of growth of microorganisms by amino acid imbalance in the medium has been reported on numerous occasions (6, 7). Exceptions to the conclusion that failure to grow on oxidizable amino acids as sole carbon source was due to the inhibition by them were observed in the case of L-arginine and L-serine. L-Arginine was quite extensively oxidized but did not support growth even though though the amino acid was not inhibitory in the presence of succinate. L-Serine, on the other hand, did prove to be inhibitory but could nevertheless serve as sole carbon source for growth. It is perhaps of significance in connection with the exceptional behavior of L-serine that, like the other four amino acids capable of serving as sole carbon sources for B_{16}, it is known to be convertible in other organisms through relatively few metabolic steps into compounds closely related to, or intermediates in, the Krebs' tricarboxyllic acid cycle (5). Most of the intermediates of this cycle can serve as sole carbon sources for the growth of B_{16}.

Manten and Rowley (8) have reported the development of resistance to inhibition by DL-valine in *Escherichia coli* strain K12, and have ascribed the phenomenon to a single-step mutation. Harper, Benton, and Elvehjem (9), on the other hand, have suggested that in the rat the appearance (in 3–4 days) of resistance to the inhibitory effect on growth of a high intake of an individual amino acid (specifically L-leucine) is the result of an adaptive mechanism.

In B_{16} it appears likely that the development of strains capable of growth with L-leucine, L-isoleucine, or L-valine as sole source of carbon was brought about by a process of mutation and selection similar to that in *E. coli*, while the recovery of the growth of B_{16} from initial inhibition by a number of naturally occurring amino acids when added to a synthetic medium containing succinate, more closely resembles the recovery of the rat from inhibition by L-leucine, and may similarly be the result of an adaptive mechanism.

It appears that both of the mechanisms that have previously been proposed to explain the development of resistance to inhibition of growth by amino acids may be present in B_{16}. However, the details of these mechanisms, as well as those of the mechanisms of the inhibitions themselves, are obscure.

Three mechanisms to explain inhibitory interrelationships between amino acids have been suggested. One of these, proposed by Prescot

al. (10), visualizes the inhibition occurring at the cell surface, where e amino acid interferes with the absorption of another that is required · growth. If the relationship between L-leucine and L-isoleucine in · growth of B_{16} be considered, it is evident that this mechanism can- t account for the effects observed as each of these amino acids can synthesized by the organism. This apparently leaves only one or · other of the mechanisms proposed by Gladstone (6) to account for · effects of these two amino acids on the growth of B_{16}. According to adstone, one of the compounds would inhibit growth by interfering th either the incorporation into bacterial protoplasm or the synthesis the other, but neither of these mechanisms appears to explain the esent observations. Thus, in a synthetic medium containing succinate, lanine, or acetate as supplementary carbon source, it was possible demonstrate only temporary inhibition of growth by L-leucine or soleucine, the eventual appearance of growth in the presence of her amino acid under these conditions apparently being due to the rmation of some product of the metabolism of succinate, L-alanine, acetate. This being so, why can L-leucine or L-isoleucine, being equally dily metabolized by B_{16}, not supply the necessary compound(s) to ercome the inhibition, when one or the other serves as sole source of rbon? One possibility is that the metabolism of these amino acids by $_{16}$ does not give rise to any of the compounds that can serve as sole urces of carbon for the growth of the organism (e.g., acetate, pyruvate, opionate, and intermediates in the TCA cycle). However, there is no idence to support such a proposal, and even if it were the correct planation it would become very difficult to explain why growth can cur when the two amino acids together are supplied as carbon source. One is forced to conclude that inhibitory effects of the amino acids nsidered must be responsible for their failure to support growth of $_{16}$ when serving as sole carbon source, and that no satisfactory explana- on of the mechanism involved can be advanced at present.

Summary

The oxidation by, and utilization of 21 amino acids as sole carbon or trogen source for growth of B_{16}, a marine bacterium with simple utritional requirements, has been investigated. Sixteen served as trogen source, 13 were readily oxidized, but only 5 served as sole rbon source.

Evidence was obtained that inhibition of growth caused the failure of

certain readily oxidized compounds to serve as either carbon or nitroger source.

Data presented indicate that an adaptive mechanism is available t the cells whereby, in the presence of a suitable additional carbon source inhibition by the naturally occurring amino acids may be overcome. I addition, it was found that under certain conditions, strains of th organism capable of growing with three of these compounds, L-leucine L-isoleucine, or L-valine, as sole carbon source may be developed.

An inhibitory interrelationship between L-leucine and L-isoleucin was demonstrated.

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NUTRITION AND METABOLISM OF MARINE BACTERIA

VI. QUANTITATIVE REQUIREMENTS FOR HALIDES, MAGNESIUM, CALCIUM, AND IRON[1]

ROBERT A. MACLEOD AND E. ONOFREY

Abstract

A study has been made of the specificity of the requirement of some marine bacteria for halides, magnesium, calcium, and iron and of their quantitative requirements for these ions in the presence and absence of related ions.

All of the organisms investigated either required or responded to the addition of Cl^- to the medium. Br^- could replace Cl^- but somewhat less readily, while I^- was toxic. For organism B-16, which required the addition of Mg^{++} but not Ca^{++} to the medium, the amount of Mg^{++} required for maximum growth varied with the level of Ca^{++} present. At low levels, a marked sparing action of Ca^{++} was evident, while at higher concentrations of Ca^{++} some antagonism between the ions was detected. Sr^{++} also spared the Mg^{++} requirement of this organism. For B-9, which required both Mg^{++} and Ca^{++}, Mg^{++} could be shown to spare the need for Ca^{++}.

An absolute requirement of one organism for Fe^{++} was demonstrated. Ni^{++} and Co^{++} showed no sparing action and proved to be toxic at a level at which Fe^{++} produced an optimum growth response.

It has been shown that an appropriate mixture of inorganic ions can replace sea water in a chemically defined medium for the growth of a number of marine bacteria. Qualitative requirements of several of the organisms for various ions have been established, and the relation of Na^+ and K^+ to their growth considered in some detail (7, 8). This report concerns an investigation of the specificity of the requirement of the organisms for halides, magnesium, calcium, and iron, and of their quantitative requirements for these ions in the presence and absence of related ions.

Methods

Organisms

The sources of the organisms and the general methods used in their study have been described (6). The four organisms used in this study have been classified as follows: B-9, a *Flavobacterium*; B-10 and B-20, *Pseudomonas*; B-16, either a *Pseudomonas* or a *Spirillum*. In the case of three of the organisms, this represents a change in their classification over that previously published.

Media and Assay Procedures

The precautions taken in the preparation of the basal medium and the assay procedures used were the same as those applied previously (7). The basal medium contained (in amounts per 10 ml. of final medium): glucose, 30 mg.; DL-α-alanine, 24 mg.; DL-aspartic acid, 9.6 mg.; glutamic acid, 12 mg.; $(NH_4)_2SO_4$, 8.7 mg.; $(NH_4)_2HPO_4$, 1.3 mg.; NaCl, 127 mg.;

[1]Manuscript received March 28, 1957.
Contribution from The Fisheries Research Board of Canada, Technological Station, Vancouver, B.C.

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$MgCl_2$, 25.3 mg.; $CaCl_2$, 5.5 mg.; $FeSO_4.(NH_4)_2SO_4$, 250.7 μg. Unless otherwise stated in the text, the inoculum medium was composed of (in amounts per 10 ml. of final medium): Bacto nutrient broth, 80 mg.; yeast extract 50 mg. plus the same salts at the same levels that were added to the basal medium.

Salts Used

In all cases, reagent grade salts were used without further purification. Analyses were made for contaminating traces of Mg^{++} in the Ca^{++} salts and of Ca^{++} in the Mg^{++} salts, using a flame photometer attachment for a Beckman DU spectrophotometer equipped with a photomultiplier. Mg^{++} estimations were made at two wave-lengths, 285.2 and 371 mμ, and Ca^{++} at 554 mμ (3).

Results

Response to Halides

When chloride salts were replaced by their corresponding sulphates or nitrates in the preparation of the basal medium one marine bacterium failed to grow and several grew more slowly unless chloride ion was added back (7).

The effect of halides on the growth of four of the marine bacteria studied previously was considered in more detail in this investigation. The response of organism B-9 to Cl^-, Br^-, and I^- is shown in Fig. 1. In this experiment the chloride salts present in the basal medium were replaced by their corresponding sulphates except in the case of Ca^{++}, which was added as the nitrate. The halides were added as their Na^+ salts. It is immediately evident that

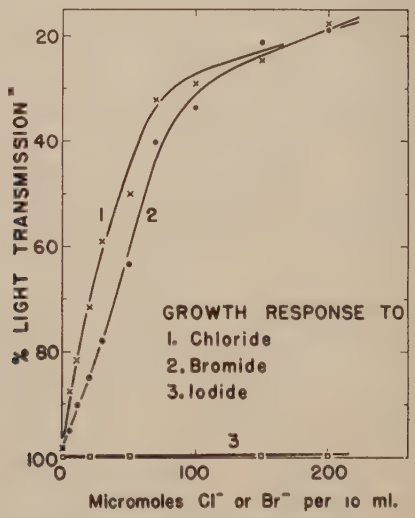

FIG. 1. The response of marine bacterium B-9 to halides.
*Evelyn colorimeter readings, 660 mμ filter, uninoculated flask = 100. Incubation time 112 hr.

mole for mole, Br^- was almost as effective as Cl^-, while I^- was without activity in promoting growth of the organism. The amount of Cl^- or Br^- required for growth varied with the incubation period. For maximum growth in the shortest time (about 72 hours for this organism) 1 millimole of Cl^- or Br was required for 10 ml. of medium. After sufficiently long incubation periods (10 days) appreciable growth occurred with 10 micromoles of added halide. Organism B-20 resembled B-9 in failing to grow without added halide even on long incubation, while B-10 grew to a limited extent under these conditions in 6 days. In all cases Br^- but not I^- could replace Cl^- almost mole for mole. I^- proved to be inhibitory.

In the case of organism B-16, only the rate of growth could be shown to be reduced by lack of added halide and then only for a brief period in the life of the culture. The response of the organism to halides is shown in Table I after two incubation periods. The amount required for maximum stimulation of growth (2 millimoles per 10 ml.) is about two-thirds of the Cl^- level in sea water.

TABLE I

GROWTH RESPONSE OF ORGANISM B-16 TO Cl^-, Br^-, AND I^-

Anion added, μM./10 ml.	Cl^-		Br^-		I^-	
	Incubation time (hr.)					
	41	66	41	66	41	66
	% incident light transmitted*					
0	90	29	91	34	95	34
10	84	33	82	39	82	30
100	80	41	79	45	96	44
500	56	43	61	36	100	99
1000	38	34	36	35	100	100
2000	29	22	35	24	100	100

*Evelyn colorimeter readings, 660 mμ filter, uninoculated flask = 100.

Response to Mg^{++} and Ca^{++}

All of the marine bacteria investigated previously failed to grow or grew to only a limited extent if Mg^{++} was omitted from the medium. Lack of added Ca^{++} prevented the growth of one organism and reduced the rate of growth of another (7).

When the quantitative requirements of the organisms for Mg^{++} and Ca^{++} were investigated it was found that the levels needed for maximum growth varied markedly, depending upon the amounts of other alkaline earth metal ions present in the medium. This is illustrated in Table II where the response of organism B-16 to Mg^{++} is shown at different levels of Ca^{++} in a basal medium from which both Mg^{++} and Ca^{++} salts had been omitted. In the absence of added Ca^{++}, the Mg^{++} level required for growth was exceptionally high. The addition of 25 micromoles of Ca^{++} reduced very remarkably, but could not replace the requirement for Mg^{++}. Sr^{++} had a

TABLE II

RESPONSE OF ORGANISM B-16 TO Mg^{++} IN THE PRESENCE AND ABSENCE OF Ca^{++}

Mg^{++}, μM./10 ml.	Ca^{++} added (μM. per 10 ml.)		
	0	25	500
	% light transmission*		
0	100	90	100
0.004	—	80	100
0.02	—	64	100
0.2	—	42	98
0.4	100	29	57
2.0	98	22	25
4.0	97	18	26
40.0	22	18	19
80.0	16	16	18

*See Table I. Incubation time 70 hours; Mg^{++} and Ca^{++} added as their chloride salts.

TABLE III

RESPONSE OF ORGANISM B-9 TO Ca^{++} AND THE SPARING ACTION OF Mg^{++}

Ca^{++}, μM./10 ml.	Mg^{++} added (μM./10 ml.)	
	20	200
	% light transmission*	
0	100	100
1.0	100	100
2.0	100	93
3.0	100	32
5.0	100	37
7.0	95	22
10.0	86	18
20.0	20	18

*See Table I. Incubation time 70 hours; Mg^{++} and Ca^{++} added as their chloride salts.

similar sparing action. Supplementing the medium with 500 micromoles of Ca^{++}, on the other hand, increased the Mg^{++} requirement over that existing when only 25 micromoles of Ca^{++} were present.

The reverse effect, the capacity of Mg^{++} to spare the requirement of an organism for Ca^{++}, is shown in Table III with organism B-9. This organism required the addition of both Mg^{++} and Ca^{++} to the medium for growth. If a small amount of Mg^{++} was added to the medium, much more Ca^{++} was required to support growth than if a higher level of Mg^{++} was present. If the sparing action of Mg^{++} shown were due to the ability of the Mg^{++} salt to introduce contaminating traces of Ca^{++}, it can be calculated that the

Mg^{++} salt would have had to contain at least 6.6% Ca^{++} to account for the effect. Direct analyses by flame spectrophotometry showed the Mg^{++} salt to contain only 0.019% Ca^{++}. Similarly, the sparing action of Ca^{++} on the response to Mg^{++} shown in Table II could not be accounted for by Mg^{++} added with the Ca^{++} since only 0.071% Mg^{++} was found in the Ca^{++} salt.

Be^{++} and Mn^{++} salts showed no capacity to replace or spare the requirement of any of the organisms tested for Mg^{++} or Ca^{++} and were found to be toxic at low concentrations.

Response to Fe^{++}

A supplement of Fe^{++} in a sea-water medium has been shown to increase the rate and extent of growth of all the marine bacteria investigated in this laboratory (7). Though complete lack of growth in the absence of added Fe^{++} could not be demonstrated at that time, a relatively complex medium apt to contain contaminating traces of Fe^{++} was used.

In an effort to demonstrate a more absolute requirement for Fe^{++}, one of the organisms, B-16, was chosen which would grow well on a medium simpler in composition than the basal. This medium contained 0.7% succinate in place of the glucose and amino acids. The growth response of the organism to Fe^{++} in this medium is shown in Fig. 2. Essentially no growth occurred in the absence of added Fe^{++} even after a 9 day incubation period, while maximum growth resulted in only 48 hours on the addition of approximately 0.3 micromoles of iron per flask. An almost identical response was obtained if a ferric salt was used to supply iron. Ni^{++} and Co^{++} showed no capacity to replace or spare the Fe^{++} requirement and were toxic when tested at the 0.2 micromole level.

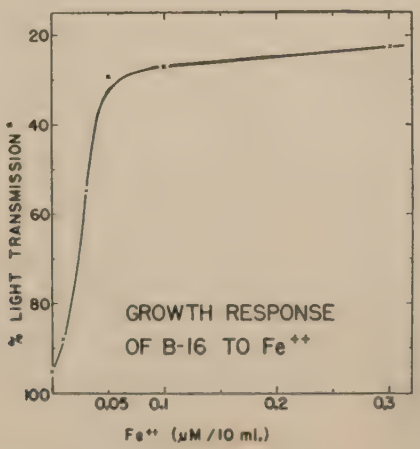

FIG. 2. Growth response of marine bacterium B-16 to Fe^{++} in a simplified synthetic medium.
*See Fig. 1. Incubation time 48 hours; Fe^{++} added as $FeSO_4.(NH_4)_2SO_4$.

Discussion

Although the importance of Cl^- in biological systems has been suspected for a considerable time, only recently has evidence been obtained that at least some cells have a requirement for this anion for growth. Broyer *et al.* (2) showed that tomato plants require Cl^- and that this requirement could be satisfied at least partially by much higher levels of Br^- while I^- proved to be toxic. There is an obvious similarity between these findings and those reported here for marine bacteria. Eagle (4) found that two types of mammalian cells in tissue culture needed Cl^- for growth, the optimum level being very similar to that required by the marine bacteria. The only other report of a requirement of bacteria for halides has been made by Brown and Gibbons (1) for the halophile *P. salinaria*.

It is of interest that so much more Cl^- was required by the marine bacteria for maximum rate of growth than was needed to permit growth after a sufficiently long incubation period. Even for organism B-16, for which no absolute requirement for Cl^- could be demonstrated, the level for maximum rate of growth was of the same order of magnitude as that for the other organisms. The response of these bacteria to halides and to Na^+ is similar in respect not only to the effect of the ions on rate and extent of growth but also to the amounts of them required for maximum rate of growth. It thus seems not unlikely that the function of Na^+ and halide may be closely related in the metabolism of marine bacteria.

The capacity of Ca^{++} to reduce so markedly the requirement of the organisms for Mg^{++} and vice versa suggests that for some but not all of the functions of these ions in the metabolism of the organisms, the two ions can be used interchangeably. The antagonism evident between the two ions at the higher concentration of Ca^{++} for organism B-16 is indicative of a situation where Mg^{++} is required specifically in a particular function and Ca^{++} can act at this site as an antimetabolite. These observations are very similar to the relationships between Mn^{++} and related ions previously recorded for lactic acid bacteria (5).

The level of iron required in the medium for maximum growth of organism B-16 is very nearly the same as that recorded for *E. coli* by Young, Begg, and Pentz (9).

Since there have been many reports of requirements of land forms of bacteria for Mg^{++}, Ca^{++}, and Fe^{++}, of the data reported here, only the response to halides appears to be unique to marine bacteria. This response to halides, like the previously reported requirement for Na^+ (7, 8), may prove to be a feature distinguishing marine bacteria from their terrestrial counterparts.

Acknowledgment

We are indebted to Dr. Einar Leifson, Loyola University, Chicago, for reviewing our classification of these organisms.

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Reprint from The Canadian Fish Culturist, No. 20, August, 1957, published by the Department of Fisheries of Canada, Ottawa.

Comparative Survival and Growth of Tagged and Untagged Brook Trout

by

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Jaw-tags have been used in a study of the movements and populations of the eastern brook trout (*Salvelinus fontinalis*) in Prince Edward Island streams (Smith, 1951; Smith and Saunders, 1956). However, possible effects of these tags upon the well-being of the trout have not been assessed. To obtain information of this sort, tagged and untagged brook trout were held in two Prince Edward Island ponds, one (Simpson's) of 2.3 and the other (Stevenson's) of 3.0 acres in area.

Procedure

On September 23-24, 1954, equal numbers (367) of tagged and untagged trout, age 1, were planted in Stevenson's Pond. The survival and growth of these trout were determined 248 days later on May 30, 1955, by draining the pond. On June 3-4, 1955, 333 tagged and 330 untagged trout, age 1, were also planted in Simpson's Pond. Assessment of survival and growth was made 108 days later on September 20-22, 1955. The ponds were drained prior to the planting, and any trout removed.

The ponds have been formed on small spring-fed streams and are readily drained to the original stream bed. The trout were efficiently recaptured on draining by trapping at the dams as the water was lowered (the majority of the fish were accounted for in this way) and by liming the stream to drive down any remaining individuals. Self-cleaning screens at the dams, and barriers at the heads of the ponds prevented escapement of the trout.

The tags employed were of the strap variety, 3.5 x 0.3 cm. in dimensions (number 2, Salt Lake Stamp Company). The tags were serially numbered. They were applied in a circular form around the mandible of the fish (Fig. 1). The ends of the tags overlapped and were pressed together, but not clinched. Rupp (Anon. 1952) and Horrocks (Anon. 1956) have devised pliers for applying this strap jaw-tag. To distinguish the trout in the event that tags were lost, the tagged individuals had the adipose and right ventral, and the untagged, the adipose and left ventral, fins removed. The fork length of each trout was measured on planting and on recovery. Except in June, 1955, at Simpson's Pond, when they were weighed in groups of ten, the weight of each trout was determined to the nearest quarter-of-an-ounce. The mean weights have been converted to grams in Table II.

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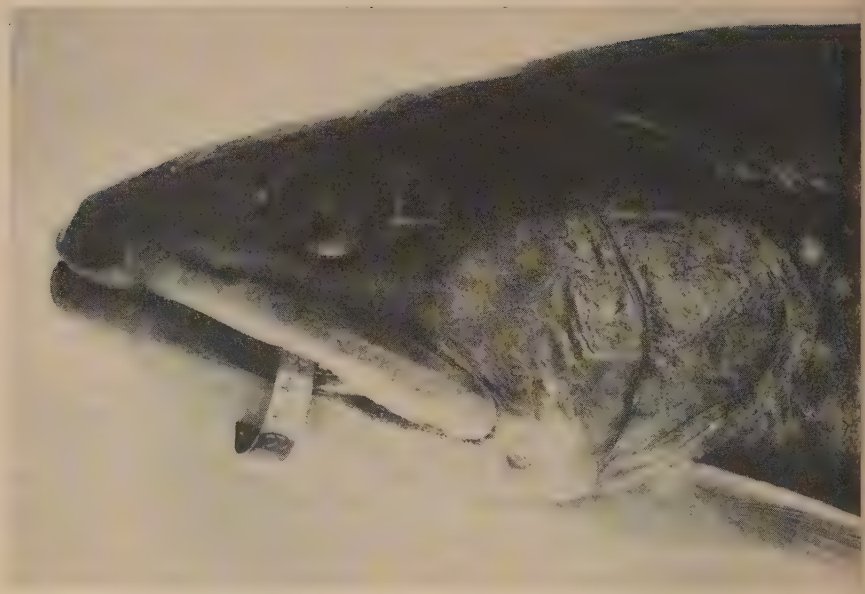

Figure 1.—Head of 24-centimetre brook trout showing attachment of circular jaw-tag.

Survival

The numbers of tagged and untagged trout that were planted and the numbers recovered on draining the ponds are given in Table I. Differences in the percentage recovery between the tagged and untagged trout were small. A somewhat better recovery of tagged trout was found when the fish were held over winter in Stevenson's Pond. The reverse situation was experienced for the summer period in Simpson's Pond.

In tagging, the trout may suffer ill-effects not only from carrying the tag, but also from the necessary handling in capture and application of the tag. In our tests the untagged trout were marked by fin-clipping. They were handled about as much as those that were tagged. The carrying of the tag was the principal difference experienced by the two groups. It may be concluded from the data that the carrying of the tag did not affect the survival of the trout adversely.

Growth

The length and weight of the tagged and untagged trout when planted and on recapture are given in Table II. In both Stevenson's and Simpson's ponds the untagged trout gained more in length and weight, but this gain was the greater in the former pond. (The difference in mean length on recovery between the tagged and untagged trout from Stevenson's Pond is significant at the 1 per cent level.) The apparent effect of the tag upon growth was most adverse when the trout were held longer and over a winter period.

In either pond both groups of trout were subjected to the same environmental conditions and had a common food supply. Almost the only difference in treatment of the two groups was the tagging. With other factors comparable, growth may be considered almost entirely as a function of feeding. Our results suggest that the jaw-tagging interfered to a moderate degree with the ability of the trout to feed and resulted in the differences in growth between the tagged and untagged fish. Rounsefell and Everhart (1953) point out that the jaw-tag "has been criticized on the grounds that there is evidence that fish so tagged do not feed properly".

The relative heaviness of the trout, as expressed by the condition factor K and determined from the relationship, weight $\times$ 100 = K (length)^3, was calculated from the mean length and weight of the trout (Table III). The untagged trout on recovery from Stevenson's Pond had the higher condition factor. The result is in keeping with that reported by Schuck (1942) upon the effects of jaw-tagging brown trout in Crystal Creek, New York. He found that tagged wild brown trout were significantly lighter for their length than untagged individuals after being at large for one and two years. However, the results from Simpson's Pond, in which the trout were held only over a summer period, are not in agreement. Actually the untagged trout were lighter in weight for their length. The differences in results suggest that the longer the tags are carried, more adverse are the effects.

It is pertinent to note that the tagged trout recovered from Stevenson's and Simpson's ponds exhibited no pathological condition arising from the tags.

Loss of Tags

It was possible to determine whether tags were lost since the tagged trout also had the adipose and right ventral fins removed. It was found that the loss of tags from trout held over winter in Stevenson's Pond was considerable. Twenty-eight per cent of the trout that had been tagged and were recaptured (195) lost the tags during the 248 days in the pond. In contrast, no tags had been lost by the tagged trout (233) recovered from Simpson's Pond after being held a 108-day summer period. The time interval at large may have been a factor in the differences in loss of tags. The trout were held in Stevenson's Pond about twice the length of time that those were retained in Simpson's.

The size of fish may also have been an important factor in the loss of tags. When recaptured in Stevenson's and Simpson's ponds the mean lengths of the tagged trout were 26.2 and 21.4 cm., respectively. At Stevenson's Pond the recaptured tagged trout still retaining the tags was 26.0 cm., while those that had lost them averaged 26.5 cm. The difference in mean length was small, but suggested that the larger individuals were more prone to lose tags. The tags were not clinched when applied. The ends of the tags may spring apart as the fish become larger and make loss of the tags easier.

Some evidence was previously obtained from trout held in rearing ponds at the Saint John, N.B., fish hatchery of the federal Department of Fisheries, that the tag employed in our studies at Stevenson's and Simpson's ponds was too small for fish approximately 30 cm. in length. Of 98 trout tagged on July 16, 1947, at a mean length of 21.7 cm., 17 per cent lost the tags by December 3 of the same year. However,

83 per cent of the tags were lost by the following April. At that time the trout still retaining the tags averaged 29.9 cm. in length. The tags that held firm were becoming embedded in the mandible. Shetter (1936) found that there was a heavy loss of tags which were not sufficiently large to accommodate increase in size of the mandible.

It was indicated by observations at Stevenson's Pond that fin-clipping should be combined with tagging to evaluate properly the effects of the tags on survival and growth. Although certain of the trout that had lost tags could be identified from wound scars which resulted from applying the tags, it was noted that such wounds apparently may heal thoroughly. Previously tagged trout could be easily overlooked.

Summary

Jaw-tags on brook trout had no demonstrable effect upon survival in cool waters and when held for periods of less than one year. However, growth was retarded, presumably through interference with feeding. Growth was more retarded in ponds when the trout were held for 248 days over a winter period, than when retained 108 days in the summer season. A growth correction factor is indicated for tagged trout, but the correction will vary in magnitude with length of time and conditions under which the trout are held. Trout which have lost tags are not always recognizable from wounds caused by tagging. Fin-clipping provides identification of such fish.

Acknowledgments

The assistance in the field of J. W. Saunders, C. R. Hayes, and Cyril Williams is gratefully acknowledged. This paper is published with permission of the Fisheries Research Board of Canada.

Table I

Survival of tagged and untagged trout in ponds

I. Stevenson's Pond

——	Planted Sept. 23-24, 1954	Recovered May 30, 1955
Number tagged	367	195 (53.1%)
Number untagged	367	186 (50.7%)

II. Simpson's Pond

——	Planted June 3-4, 1955	Recovered Sept. 20-22, 1955
Number tagged	333	233 (70.3%)
Number untagged	330	244 (73.9%)

Table II

Mean length and weight, with standard deviation, of tagged and untagged trout in ponds. Length in centimetres and weight in grams. Number of trout in samples in brackets.

I. Stevenson's Pond

	When planted Sept. 23-24, 1954		When recovered May 30, 1955	
	Tagged	Untagged	Tagged	Untagged
Mean length	22.6 ± 1.72 (200)	22.5 ± 1.95 (200)	26.2 ± 1.87 (191)	26.7 ± 1.75 (188)
Mean weight	139 ± 35.7 (200)	136 ± 39.1 (200)	203 ± 51.9 (190)	221 ± 47.3 (185)
Gain in length	—	—	3.6	4.2
Gain in weight	—	—	64	85

II. Simpson's Pond

	When planted June 3-4, 1955		When recovered Sept. 20-22, 1955	
	Tagged	Untagged	Tagged	Untagged
Mean length	17.1 ± 1.88 (333)	16.8 ± 2.45 (330)	21.4 ± 1.89 (230)	21.6 ± 2.58 (240)
Mean weight	62 (333)	60 (330)	122 ± 36.0 (178)	122 ± 46.2 (182)
Gain in length	—	—	4.3	4.6
Gain in weight	—	—	60	62

Table III

Relative heaviness, expressed by the condition factor K, of tagged and untagged trout.

I. Stevenson's Pond

	When planted	When recovered
Tagged	1.20	1.13
Untagged	1.20	1.17

II. Simpson's Pond

Tagged	1.25	1.24
Untagged	1.26	1.21

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EDMOND CLOUTIER, C.M.G., O.A., D.S.P.
QUEEN'S PRINTER AND CONTROLLER OF STATIONERY
OTTAWA, 1957

Reprint from The Canadian Fish Culturist, No. 20, August, 1957, published by the Department of Fisheries of Canada, Ottawa.

Lea's Hydrostatic Tag on Brook Trout and Atlantic Salmon Smolts

by

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Einar Lea first demonstrated the hydrostatic tag at a meeting of the International ncil for the Exploration of the Sea in 1948. Since that time this tag has been used by mber of investigators on several species of fish. Dannevig (1953) obtained better rns with hydrostatic than either disk or strap tags in his studies of Norwegian However, of more interest to us is the use of the hydrostatic tag on salmonoids. nt (1951, 1953) and Went and Vickers (1953) employed Lea's tag to advantage in ing the movements of adult Atlantic salmon along the Irish coasts. Vibert (1953) ed salmon smolts in southern France. A few of these smolts were later recaptured nackerel fishermen well to sea in the Atlantic. Jensen (1955) recovered as high 4.8 per cent of rainbow trout tagged and liberated in Roskild Fjord, Denmark.

In 1950 the hydrostatic tag was used on brook trout and smolts of the Atlantic ion at Ellerslie Brook, Prince Edward Island. Since jaw tags had been and were ently being employed on brook trout at Ellerslie, a comparison of results from two es of tagging was possible. This article presents the results.

Lea's Hydrostatic Tag

The hydrostatic tag is illustrated in Figure 1. It has been previously described on., 1953; Rounsefeld and Everhart, 1953; Went, 1951). Briefly, the tag consists small celluloid cylinder, plugged at both ends, and containing written instructions he finder. It is attached by a bridle of stainless steel to a wire pin which pierces flesh of the fish, usually just anterior to the dorsal fin (Fig. 2). Nylon line has been l for attachment in some instances (Collyer, 1954; Dannevig, 1953; Jensen, 1955). specific gravity of Lea's tag is somewhat less than that of water.

The tags used at Ellerslie Brook were obtained from Mr. Lea. They were three timetres long and four millimetres in diameter and coloured yellow with blue-tipped s. Printed on the tag were the words "Canada", "Reward", and "cut ends, sage inside", and a serial number.

Tagging

Tagging was done in connection with a study of the movements and populations Ellerslie Brook of the brook trout primarily and the Atlantic salmon secondarily th, 1951). Fish are captured in a two-way fish trap (trap A) as they move between

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salt water and Ellerslie Brook. A second similar trap (trap B), situated 650 yar upstream, captures fish as they move between the lower and upper sections of th brook. The traps have been described previously and their efficiency evaluated (Smi and Saunders, 1956).

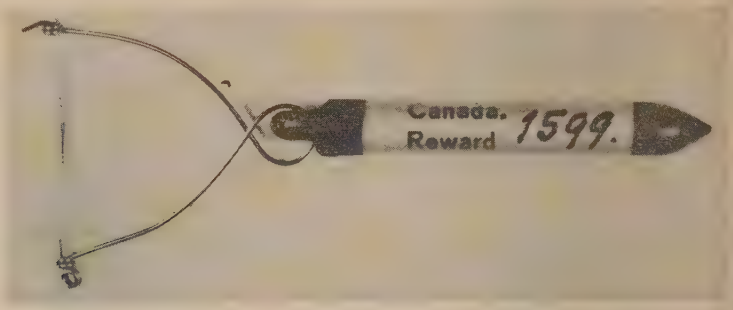

Figure 1.—Lea's hydrostatic tag.

Figure 2.—Wooden "boot" in which trout were held during tagging.

Fish were held in a wooden "boot" while the hydrostatic tag was attache (Fig. 2). A continuous flow of water was supplied through a hole at the head of th "boot". The forward end of the "boot" was tilted downward to insure that the hea of the fish was entirely submerged. Three "boots" with holes of different diamete were used. It was necessary to have the hole sufficiently large so as not to interfe with movements of the opercula in respiration, yet small enough to retain the fi well. The fish remained quiet during the entire tagging operation.

The following operations were involved in the tagging. The flesh of the fis just anterior to the dorsal fin, was pierced with a number 18 hypodermic needle. right-angle bend was made at one end of the pin. The straight end of the pin w threaded through one loop of the bridle and then through the hypodermic need The needle was withdrawn, the pin cut to the desired length and the other loop of t bridle slipped over the pin. Finally the straight end of the pin was bent, using tw needle-nosed pliers, one to hold the pin rigidly, the other to bend it.

From June 14 to July 4, 1950, hydrostatic tags were placed on 100 brook tro as they moved into Ellerslie Brook through trap A. These trout had an average fo length of 18.4 $\pm$ 0.62 cm. Similarly, in the period November 16 to 20, 1950, 77 tro

e tagged as they went downstream through trap B, and 23 others when they were n going to salt water through trap A. The mean fork length of these two groups rout were 16.0 ± 1.60 and 16.3 ± 2.87 cm. respectively.

During April and May, 1951, hydrostatic tags were also applied to 493 salmon lts as they ran to sea through trap A. These salmon had an average fork length 3.6 ± 0.57 cm.

From June 1 to July 27, 1950, 152 trout were jaw-tagged when they moved into brook through trap A. During the month of November, 1950, jaw tags were also led to 312 trout as they ran downstream through trap B and 261 as they went to water through trap A. This tagging was a continuation of a programme already er way at Ellerslie Brook whereby all trout moving through the traps, up- or down- am, were tagged. The jaw tag was of the strap variety, applied in a circular form nd the mandible of the trout (Smith, 1957).

Recapture of Tagged Trout

Records of recapture of tagged trout were obtained in a number of ways: (1) from traps, (2) by an annual creel census maintained on the brook and estuary, (3) during ulation studies in the brook, and (4) by capture in commercial smelt nets in the uary.

Table I

Recaptures of trout bearing hydrostatic tags.

Manner of recapture	Number recaptured and time at large		
	<1 week	2-4 weeks	<4 weeks
I—Of 100 trout tagged in A trap going upstream			
gled	9	4	2
raps	1	0	1
ing population studies	0	1	1
ill-nets	0	0	1
II—Of 77 trout tagged in B trap going downstream			
gled	0	0	4
raps	24	4	7
ill-nets	6	0	0
III—Of 23 trout tagged in A trap going to salt water			
raps	0	2	1
ill-nets	2	0	0

Table II

Comparison of number of recaptures of trout bearing hydrostatic and jaw tags

Place tagged	Number tagged	Recaptures		Number of recapture after 100 days at larg
		Number	Percentage	
I—With hydrostatic tags				
A trap up	100	20	20	1
B trap down	77	45	58	5
A trap down	23	5	22	1
Totals	200	70	35	7
II—With jaw tags				
A trap up	152	93	61	36
B trap down	312	214	69	111
A trap down	261	179	69	94
Totals	725	486	67	241

Hydrostatic tags.

Data on the recapture of trout bearing hydrostatic tags are summarized in Tab I and II. Seven tagged trout were recaptured twice. The first time was in trap as they ran to salt water. However, only the final recapture is recorded in the tabl

There were 20 recaptures from the 100 trout tagged as they entered the bro The majority (13) of these recaptures was made by anglers within a month of t tagging dates. The longest period that any of this group of trout was at liberty betwe tagging and recapture was 150 days.

Forty-five (58 per cent) of the 77 trout tagged in trap B as they moved downstre were recaptured. These trout were tagged in November when there is a gene movement from the brook to salt water. Accordingly, it is not surprising that t greater number of recoveries were made at the mouth of the stream in trap A wit a few days. Six individuals were subsequently taken in gill-nets in the estuary withi period of a week. Five from this group of 77 trout were at liberty 132 to 151 da between tagging and last recapture.

Five recaptures were made from the 23 trout tagged in trap A when running salt water. Two individuals were captured within a week in gill-nets. The oth three were taken in trap A as they re-entered the brook, one after being in salt wa for 220 days.

In summary, 35 per cent of the trout bearing hydrostatic tags were recaptured. owever, the majority of these trout were at liberty for the short period of less than one nth. Recovery of tagged trout after having run to salt water was poor. Out of 0 trout with hydrostatic tags, only seven upon recapture had been at large for more an 100 days.

w tags.

As shown in Table II, 67 per cent of the trout that were jaw-tagged as they ved up- and downstream through the traps were recaptured. There was little ference in the percentage recovery between those tagged going upstream and those it were running downstream and into salt water. In contrast to the returns th hydrostatic tags, a large proportion (50 per cent) of the jaw-tagged trout were at erty over 100 days before recapture.

Recapture of Tagged Salmon

There are no records that any of the 497 smolts bearing hydrostatic tags were captured. Twenty adult salmon entered Ellerslie Brook during the fall of 1953 and in 1954. None of these fish showed any evidence of having been tagged. It is ssible that tags could have been shed without leaving recognizable scars. However, eful examination of each salmon failed to reveal any. No capture of salmon with drostatic tags has been reported from the commercial salmon fisheries of the Gulf St. Lawrence area.

Two hydrostatic tags that had become free from the fish were found. One was ked up on the shore of Lennox Island in Malpeque Bay at a point about two miles m the mouth of Ellerslie Brook. The other was found on the beach at Percé, Quebec, distance (shortest) of about 150 miles from Ellerslie. Since the tag is hydrostatic it uld act in the manner of a drift bottle after being freed from the fish.

Summary

It was observed that the bridle of the hydrostatic tag became fouled with aquatic getation, especially filamentous algae, in Ellerslie Brook and estuary. In the brook, trout, including tagged individuals, sought hiding places when disturbed. In so ng it seems probable that snagging of the bridle would frequently occur. It was ther observed that the hydrostatic tag and its bridle tended to ride to one or the er side of the fish. As a result, the flesh of the fish was abraded by the end of the dle where twisted around the pin and by the sharp free end of the pin itself. These ditions would militate against the survival of the fish and the retention of the tag.

The brightly-coloured hydrostatic tags were surprisingly conspicuous in the ar water of Ellerslie Brook. The bright colours were intentionally used to aid in overy of the tags, yet their conspicuousness might attract undesirable attention. this regard it was noted that trout struck at the hydrostatic tags carried by other lividuals.

The fortuitous recovery of two unattached hydrostatic tags that had been place on salmon smolts has been noted. Five additional unattached tags were found Ellerslie Brook. These had been put on trout. However, the loss of these tags d not necessarily indicate death of the fish as shown by the capture of seven previous tagged trout with scars at the point of attachment of the tags. It is pertinent to no that jaw tags were shed by trout without apparent injury to the fish. Of 1,625 tro that had been jaw-tagged and subsequently recaptured in trap A during 1950, (4.3 per cent) had lost the tag. (In applying both the hydrostatic and jaw tags t adipose fins were removed, which aided in spotting the previously tagged fish.)

Although tried on only a few salmon smolts, it was found that the tendency the hydrostatic tag and its bridle to slip sideways was largely prevented by placi two small celluloid disks on the pin or either side of the fish and inside the attachme of the bridle. The disks added some encumbrance to the tag. Attachment with nyl line may have lessened the difficulty. Jensen (1955) experienced more recaptures rainbow trout when nylon was used to attach hydrostatic tags. On the other han Collyer (1954) found that attachment with nylon gave no better results than wh wire was employed in tagging the yellowtail (*Seriola dorsalis*).

The hydrostatic proved inferior to the jaw tag when used on trout at Ellers Brook. Fouling and snagging of the tag, more to be experienced in the confined quarte of Ellerslie Brook and estuary than in open waters, were important factors conditioni the results.

Acknowledgment

The assistance of J. W. Saunders, C. R. Hayes and Cyril Williams is gratefull acknowledged. This paper is published with permission of The Fisheries Resear Board of Canada.

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QUEEN'S PRINTER AND CONTROLLER OF STATIONERY
OTTAWA, 1957

...ated from COPEIA, 1967, No. 3, pp. 252–253, August 26
...d in U.S.A.

...UPTIAL OR PRE-NUPTIAL BEHAVIOUR ...THE SHAD, *ALOSA SAPIDISSIMA* (WIL-...).—Mr. H. C. White (recently retired from ...Fishery Research Board staff) and the author ...rved a peculiar behaviour of shad from the ...ge across the Southwest Margaree River, Nova ...ia, at Scotsville (N. Lat. 46°, 12′; E. Long. ...9′) about three o'clock in the afternoon on ...20, 1935. This was described in some detail in ...unpublished Biological Stations report (No. ... filed shortly afterwards by the author. To the ... of the writer's knowledge nothing similar has ... recorded by students of this species.

...he Scotsville bridge is about 1 mile below the ...t where Lake Ainslie, a clear, shallow lake 10 ...s long and 5 miles wide, suddenly narrows and ...omes the river. At that time the water surface ... approximately 8 feet below the bridge, the ...th 7 feet at mid-stream, the flow about 40 feet ...inute, the temperature 18°C and the visibility ...ugh the clear, colourless water excellent because ...as a bright, calm day. The school of shad (25 fish ...ated) studied was first noticed when it was about ...eet below the bridge. It was composed entirely ...dult shad of an almost uniform size 20 to 30 ...es long swimming 3 to 4 feet below the surface. ...re was no doubt about their specific identity ...use in the next few minutes we were able to ...w them constantly and observe their general ...uration, large scales and the series of dusky ...ts along the sides.

When first sighted the fish were swimming rapidly ...stream in single file behind a leader which, so ...as we could determine, maintained the leader-... throughout the period of our observations. ...en they arrived close to the bridge the line ...kened its speed and began a counter-clockwise ...ling (6 to 8 feet diameter). This continued for ...ghly 1½ minutes but as it proceeded the speed ...reased gradually and the diameter of the circle ...reased until the arched bodies of the fish were ...rling at a startling rate in a path no more than ... feet in diameter. The crowding was such that ... fish was frequently bumping its nose into the ... immediately in front. This, apparently, some-...es displaced, but did not dislodge, scales which ...ained as shining silver spots on the sides of the ...

When the speed of whirling at the center reached ...at seemed an incredible speed, the seemingly ...ess leader flashed off to the right then headed straight up-river for about 50 feet and again began circling slowly in mid-stream. The others followed, trailing off in single file, and the whole process just described was re-enacted. As it went on the current carried the school back downstream to the bridge almost but not quite to the place where the previous gyration had ended. In the 10 minutes we were able to view them the fish staged this peculiar performance 6 times without any observable difference in pattern of behaviour. It was apparently continued further up-stream but surface reflections made it impossible for us to observe it.

Hoping to get a specimen for positive identification Mr. White borrowed a fishing rod from a lad who was on the bridge and tried to entice the fish with a hook baited with angle worms. They displayed not the slightest interest. Mr. White was equally unsuccessful in trying to "jig" them with a bare hook. The fish were not frightened by this at all nor by beating the surface of the water with the rod itself. Later, the writer identified a typical specimen taken July 9, 1935, in an alewife brush weir set just below Scotsville.

Weirmen also recognized the fish as shad and stated that the 1935 run was the largest for many years. Villagers did not know the species. Several of them had previously reported seeing 30 "salmon" below the bridge on the afternoon of June 13, 1935, which would not strike fly or worm and circled in a peculiar way for half an hour. Undoubtedly the "salmon" were shad and their behaviour the same as has just been described.

Despite the turmoil, there was no suggestion of cloudiness of the water about the fish which might possibly have been expected if these fish had been spawning. Besides this, shad spawning ordinarily takes place at night (Leim, 1924, Contrib. Canadian Biol., 2 (11): 163–284). Furthermore the whirling was quite different from "washing", the shad's frequently-described accessory behaviour at spawning (Mansueti and Kolb, 1953, Maryland Dept Res. Educ., 97: 1–293); washing takes place close to the surface and seems to involve single fish only. For these reasons it might be concluded that the Margaree shad were not spawning, but this is not certain. We were of the opinion, however, by the religiousness of this group performance that it is a regular behaviour pattern of shad and not a series of chance incidents.

In seeking an explanation for what we witnessed

Mr. White suggests that it may have been a device for natural selection of vigorous parent stock; that the leader may have been a ripe female, her followers males competing for her much as drones compete for the queen bee during her mating flight and that mating may occur between the leader and the most vigorous male, either during the circling process or later and more leisurely when other m have wearied of the mad chase the female has them.

The author acknowledges assistance in prepa this account from Mr. H. C. White and Dr. A. Leim.—J. C. Medcof, *Fisheries Research Boar Canada, St. Andrews, New Brunswick.*

ON SOME PELAGIC POLYCHAETA FROM THE NORTHEAST PACIFIC NORTH OF LATITUDE 40° N. AND EAST OF LONGITUDE 175° W.[1]

E. Berkeley and C. Berkeley[2]

Abstract

Two species (*Otopsis longipes* Ditlevsen and *Epidiopatra hupferiana* Augener) new to the Pacific Ocean and four new to it north of latitude 40° N. (*Phalocrophorus pictus* Greef, *Plotohelmis tenuis* (Apstein), *Tomopteris cavallii* Rosa, and *Travisiopsis lobifera* Levinsen) are recorded. Four others, one of which (*Typhloscolex mülleri* Busch) was taken at a more northerly latitude in the northeast Pacific than previously, are also listed.

Introduction

During the years 1955 and 1956 the vessels engaged in the survey activities of the Fisheries Research Board of Canada in the northeast Pacific collected plankton samples at a number of stations. We were entrusted with the examination of the polychaetes secured. This paper contains records of the species which have been identified together with those of a few others collected independently.

All but one of the samples were taken in open nets towed from a known depth to the surface, so that the exact depth of any particular capture cannot be given. All were taken during the summer months (June to August).

The collection comprises 10 species, two of which (*Otopsis longipes* Ditlevsen and *Epidiopatra hupferiana* Augener) are new to the Pacific Ocean and four (*Phalocrophorus pictus* Greef, *Plotohelmis tenuis* (Apstein), *Tomopteris cavallii* Rosa, and *Travisiopsis lobifera* Levinsen) new to the eastern side of that ocean north of latitude 40° N. Of the remainder, one (*Typhloscolex mülleri* Busch) was taken at a more northerly latitude than previously in the northeast Pacific.

Phyllodocidae

Phalocrophorus pictus Greef. Fauvel (9, p. 196)

M. V. *Key West II*: 56° N. lat., 140° 07′ W. long., 150–0 m.

A single specimen 6.7 mm. long agrees with both Fauvel's description and those of Reibisch (14, p. 10, and 15, p. 2).

The species has been recorded from the Pacific under the name *P. maculatus* Treadwell (17, p. 34), which Hartman (11, p. 276) shows is a synonym of *P. pictus* Greef. Treadwell's records extend as far north as latitude 40° N. off the coast of California, and Uschakov (19, p. 294) records the species from about the same latitude off the coast of Japan. The distribution is now

[1]Manuscript received May 6, 1957.
Contribution from the Fisheries Research Board of Canada, Biological Station, Nanaimo, B.C.

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extended considerably farther north in the Pacific. In the Atlantic a single instance of its occurrence as far north as latitude 60° N. is recorded (Reibisch (14, p. 10, and 15, p. 2)), but the main distribution is south of latitude 40° N.

Otopsidae

Otopsis longipes Ditlevsen. Ditlevsen (8, p. 67)

The genus *Otopsis* was established as the sole representative of a family, *Otopsidae*, by Ditlevsen (8, p. 67), in 1915, with the present species as type. The description was based on two fragments of an incomplete specimen taken off the southwest coast of Iceland in 843 fathoms. The only subsequent record until the present one is that of a variety *pacifica*, taken by Uschakov (18, p. 202) in the Okhotsk Sea in 1276–1366 m. The distinguishing character of that variety is absent from the present specimen, which was collected in a deep haul, from about 200 fathoms to surface, in the Gulf of Georgia (approximate bearings 49° N. lat., 123° 50′ W. long.) in 1927. Its identity has only recently been established. It agrees completely with Ditlevsen's account except that there are setae, which he does not mention, beneath the single cirrus on the segment immediately following the buccal segment. It is incomplete posteriorly. The cephalic region is followed by 18 segments and these jointly measure about 14 mm. as preserved. The body width is about 5 mm. Eggs are present in the body cavity.

Alciopidae

Plotohelmis tenuis (Apstein)

Corynocephalus tenuis Apstein. Apstein (1, p. 14)

M. V. *Key West II*: 52° 00′ N. lat., 137° 50′ W. long., 150–0 m.;
46° 08′ N. lat., 127° 01′ W. long., 150–0 m.;
43° 47′ N. lat., 125° 03′ W. long., 150–0 m.;
51° 51′ N. lat., 132° 00′ W. long., 150–0 m.;
44° 00′ N. lat., 127° 02′ W. long., 150–0 m.;
42° 05′ N. lat., 127° 35′ W. long., 150–0 m.

This is the species most frequently taken in the collection with the exception of the Tomopteridae. All the specimens are fragmentary and usually much curled, but several fragments reach at least 50 mm. in length as preserved. The maximum width is about 0.5 mm. excluding the parapodia. The specimens agree in all respects but one with Apstein's description of *Corynocephalus tenuis*, the distinctive characters being the eyes, which are set in such a way that their axes meet in a right angle, the long parapodium carrying a bunch of very long and slender capillary setae, and a narrow dorsal cirrus. They differ from the description in having at least some of the capillaries composite. The terminal pieces are extremely attenuate and difficult to see and in some the junction cannot be determined with certainty. The genus *Plotohelmis* Chamberlin (6, p. 143) is characterized by having composite setae. Dales (7, p. 439) transfers the species to this genus and says it is the commonest

alciopid in the surface waters off California. His and the present records are the only ones from the Pacific area. *Corynocephalus tenuis* is recorded by Apstein (1, pp. 22 and 26) from the south Atlantic and Mediterranean.

Callizona angelini (Kinberg). Fauvel (9, p. 215)

H. M. C. S. *New Glasgow:* 51° 58′ N. lat., 169° 40′ W. long., 150–0 m.

A single example is about 50 mm. long and about 4 mm. wide over the setae at the widest point as preserved. It is complete and typical. Considerable brown coloration remains on the dorsal surface with darker intersegmental lines and segmental glands. The ventral surface is yellow. The eyes are reddish brown.

This species was originally described by Kinberg (12, p. 243) under the generic name *Kronia* from the southern Pacific ("China Sea, latitude 20°"). It has since been recorded from southern Pacific latitudes as *Rhynchonerella* (11, p. 277) and we have recently identified it in pelagic material taken off the northwest coast of South America by Mr. W. L. Klawe of the Inter-American Tropical Tuna Commission (unpublished).

The first two records from the northern Pacific are those of Berkeley (3, p. 76) taken in tows from 100 fathoms and 50 fathoms to surface respectively off Vancouver Island (approximate bearings 50° N. lat., 125° W. long.). More recently further specimens have been recorded in tows in the same region (unpublished). The present find is only a little farther north, but considerably farther west. Dales (7, p. 439) records the species as *Rhynchonerella* from Monterey Bay and up to latitude 45° N.

The species is recorded in the Atlantic as far north as latitude 60° N. (Apstein 1, p. 18 and Table 8). It is known from the coast of Ireland (Southern 16, p. 4), in the Mediterranean, and in the Indian Ocean.

Tomopteridae

Tomopteris septentrionalis Quatrefages. Fauvel (9, p. 226)

This is by far the commonest species in the collection. It has been found in samples from over 150 stations distributed throughout the region covered. It appears to be as widely distributed in the north Pacific as it is in the north Atlantic area. Our northernmost record is from latitude 58° N. and our most westerly from longitude 170° W. We have indicated only these two stations in the annexed distribution chart to avoid overcrowding it. Many of the examples examined have pigmented hyaline glands as described by Wesenberg-Lund (20, p. 5). Some are unusually large, running up to as much as 22 mm. in length. Uschakov (19, p. 282) records the species from about latitude 60° N. in the Bering Sea and Treadwell (17, Map 4) from about latitude 50° N. off the Aleutian Islands. Dales (7, p. 440) finds it the commonest tomopterid in the Monterey, California, region.

Tomopteris cavallii Rosa. Fauvel (9, p. 222)

M. V. Challenger: 48° 49′ N. lat., 126° 40′ W. long., 150–0 m.;
48′ 38′ N. lat., 126° 32′ W. long., 150–0 m.;
52° 00′ N. lat., 132° 00′ W. long., 150–0 m.

M. V. Key West II: 43° 47′ N. lat., 125° 03′ W. long., 150–0 m.
M. V. Challenger: 50° 00′ N. lat., 130° 00′ W. long., 150–0 m.;
54° 00′ N. lat., 137° 30′ W. long., 150–0 m.;
50° 00′ N. lat., 140° 00′ W. long., 150–0 m.;
53° 06′ N. lat., 139° 56′ W. long., 150–0 m.

This species is new to the region. It is far less common than *T. septentrionalis*. It was accompanied by examples of that species in the last four of the stations enumerated above, but in the others only *T. cavallii* was secured. Probably this is without significance. The yellow coloration of the pinnules to which Southern (16, p. 29) refers was a marked characteristic of some of the specimens.

Tomopteris (*Johnstonella*) *renata* Berkeley. Berkeley (4, p. 26)

It is remarkable that this species is not in the collection. Hitherto it has been taken on the eastern side of the north Pacific only fairly closely inshore, and this may be a determining factor. Uschakov (18, p. 110), however, records it off southeast Kamchatka, Okhotsk Sea, and Bering Sea, all from considerable depths. Dales (7, p. 440) has taken *T. pacifica* Izuka off Monterey, California, and regards it as synonymous with *T. renata* Berkeley. We doubt this synonymy. The most conspicuous difference is in the posterior region of the body. In *T. renata* there is an abrupt transition from the body region to the tail, which consists of 12 segments with rosette-like pigmented spots at the base of each. In *T. pacifica* the body region tapers gradually into the tail which has 11 segments with pigment spots on eight. Moreover *T. renata* is very much larger than *T. pacifica*, has more body segments, and there are differences in the lengths of the first pair of tentacular cirri relative to the tentacles and in those of the second pair relative to the body length. Uschakov (19, p. 285) records both *T. renata* and *T. pacifica* from the north west Pacific, the former fairly commonly north of latitude 50° N., the latter in a single instance at about latitude 45° N.

Typhloscolecidae

Typhloscolex mülleri Busch. Fauvel (9, p. 226)
H. M. C. S. *Ste. Thérèse*: 50° 50′ N. lat., 160° 59′ W. long., 400–0 and 200–0 m.;
51° 13′ N. lat., 167° 58′ W. long., 100–0 m.
M. V. Challenger: 55° 43′ N. lat., 140° 21′ W. long., surface.

This species has rarely been reported from the north Pacific area. The first records are those of Berkeley (3, p. 76) from the west coast of Vancouver Island. One of these was taken in a depth haul from 50 fathoms off Cape Beale, the other in a surface tow off Nootka.

Only single individuals (5 mm. and 4 mm. long) were obtained from each of the plankton collections from which the present examples were derived. The first, taken in a closing net, was certainly secured at a depth of at least 200 m., the second, in a tow from 100 m. to the surface, may have been caught anywhere from 100 m. upwards, and the third was taken at the surface.

Recently Dales (7, p. 442) has reported a single specimen from Monterey, California, and others from north of that locality. Uschakov (18, p. 112) records the species from the southeast coast of Alaska and, from approximately the same latitude as the present records, from the northeast Pacific (19, p. 286).

Typhloscolex mülleri is characteristic of warm seas. It is widely distributed in the Atlantic south of latitude 40° N. The most northerly record in that ocean is off Newfoundland at about the same latitude as the present records (Reibisch (14, p. 8)).

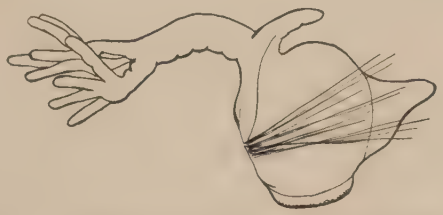

FIG. 1. Epidiopatra hupferiana, fifth parapodium.

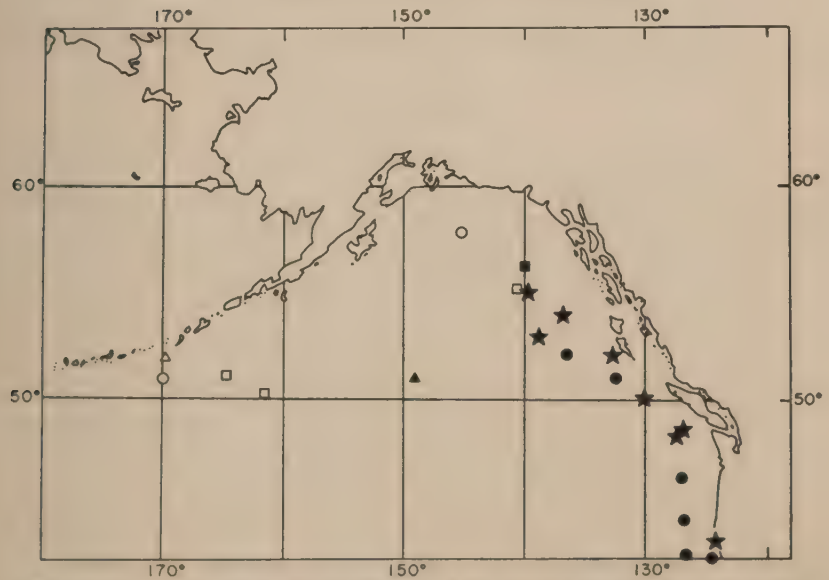

FIG. 2. Chart illustrating the distribution of the species recorded (excepting *Otopsis longipes* Ditlevsen and *Epidiopatra hupferiana* Augener). ■ *Phalocrophorus pictus* Greef. ● *Plotohelmis tenuis* (Apstein). △ *Callizona angelini* (Kinberg). ○ *Tomopteris septentrionalis*. Quatrefages (extreme north and west stations only). ★ *Tomopteris cavallii* Rosa. □ *Typhloscolex mülleri* Busch. ▲ *Travisiopsis lobifera* Levinsen.

Travisiopsis lobifera Levinsen. Fauvel (9, p. 229, and 10, p. 66)

H. M. C. S. *New Glasgow*: 51° 21′ N. lat., 149° 21′ W. long., 150–0 m.

A single well preserved example of this species is 15–16 mm. long, 1.5 mm. wide, and consists of 21 segments. The characteristic cordiform cirri are complete. The specimen has no color as preserved. The prostomium is pointed, the anal cirri short and subcircular.

Chamberlin's description (6, p. 155) of *Plotobia simplex* agrees closely with the present species; Fauvel (10, p. 66) regards them as probably synonymous. If this is so the earliest records in the Pacific are from the neighborhood of the Galapagos Islands. Dales (7, p. 442) states that it is "the commonest species of *Travisiopsis* in Californian waters". Uschakov (19, p. 286) records it in the northwest Pacific at about 40° N. lat., 155° E. long. The present is the most northerly Pacific record. It is known from the Azores, Canary Islands, the Mediterranean, and the Arabian Sea (10, p. 67).

Eunicidae

Epidiopatra hupferiana Augener. Augener (2, p. 355)
M. V. *Loligo*: 54′ 10′ N. lat., 130° 40′ W. lat., 100–0 feet.

The capture of this specimen has already been recorded (5, p. 748). The genus is a rare one, the only previous records of its occurrence being off the west (2, p. 355) and the south (13, p. 125) coasts of Africa. A pelagic representative has never previously been encountered. We repeat the record here because of its interest in these respects and to illustrate the remarkable branchiferous parapodium.

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COUNTING FENCE OF NETTING

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Abstract

A two-way fence of netting is described. It has been used for counting ascending adult salmon *(Salmo salar)* and descending salmon smolts in Newfoundland rivers near the mouth where depths have ranged from 1 to 9 feet. The traps and barriers are constructed in sections which can be easily dismantled and transported to another river. Also sections of netting in the barriers which become clogged with debris during flood conditions can be readily replaced with clean sections.

Introduction

A program of general surveys of salmon *(Salmo salar)* resources on some of Newfoundland's major rivers was initiated in 1951. One river was surveyed each year so as to cover a large number of rivers in a relatively short time. A counting fence (weir and trap) that could be easily installed and readily transported from river to river was needed. Fences of many types and variations have been described by O'Malley (1920); Foerster (1929); Shetter (1938); White (1939); Pritchard (1944); Brett (1948); Hayes (1953); Whalls, Proshek, and Shetter (1955); and Smith and Saunders (1956). In 1946 Brett (1948) used a netting fence and a central trap to capture migrating young sockeye salmon *(Oncorhynchus nerka)* in Lakelse River, British Columbia. Netting appeared to be a more suitable material for temporary fences than pickets, iron rods, or wire cloth.

A short fence of netting was first used in Newfoundland on Black River in 1946 to count salmon entering the river after an opening had been made in a dam which completely barred the river (Figure 1). Since then one-way fences of netting to count ascending salmon have been used on Gander River in 1951 and on Terra Nova River in 1952. A two-way fence of netting to count both ascending salmon and descending smolts was first used on Bay du Nord River in 1953 and on Little Codroy River in 1954. It is the two-way fence that is described in this paper. Its special feature is its suitability for construction of barriers and traps of small units which are easy to install, to replace, or to transport.

The width of Bay du Nord River where the fence was operated was 880 feet. The depth of water at the trap ranged from 1 to 9 feet during the season of 1954. The highest flow during installation of the fence

Reprinted from Volume 86 (1956), Transactions of the American Fisheries Society
Published 1957. Printed in U.S.A.

FRB No. 492

FIGURE 1.—Map of the southern half of Newfoundland showing locations of counting fences on salmon rivers.

in 1953 was 5,290 cubic feet per second. The highest during the operation of smolt fence was 2,850 cubic feet per second and the highest during the operation of the salmon fence was 2,120 cubic feet per second.

DESCRIPTION OF FENCE

The fence under consideration is roughly X-shaped (Figure 2). It consists of two separate traps, placed side by side in midstream, and four arms. From the upper end of the pair of traps an arm extends upstream to each bank, and from the lower end one extends downstream to each bank. The two upper arms lead smolts moving downstream into one of the traps, and the two lower arms lead adult salmon migrating upstream into the other.

Each arm of the fence consists of sections of netting suspended from a steel cable which is supported by a number of piers. The angle of the arms to the direction of flow is approximately 45°. The actual angles of the four arms of the fence on Bay due Nord River were 45°, 50°, 50°, and 30°. Advantage is taken of projections in the river bank to shorten the arms rather than adhering rigidly to the 45° angle.

TRAPS

The salmon and smolt traps are similar in construction. The outside dimensions of the trap (Figure 3A) are: length 10 feet 3 inches, width

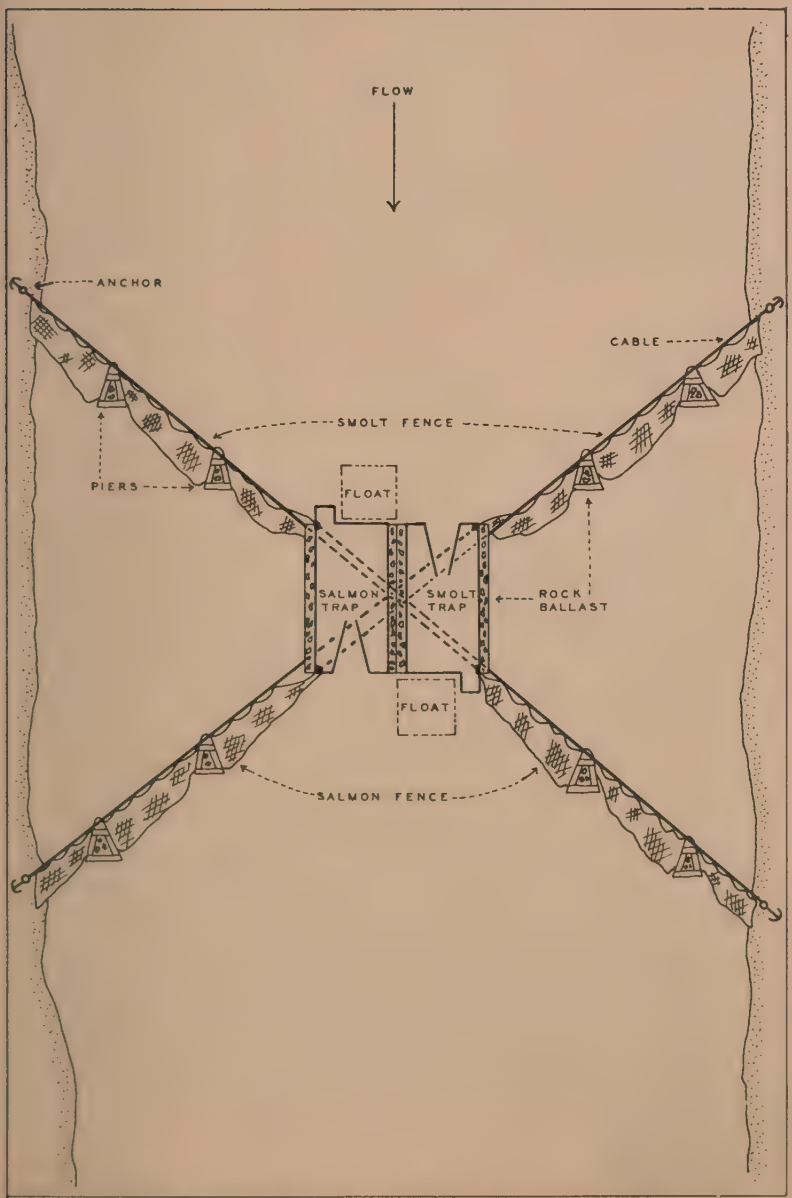

FIGURE 2.—Plan of two-way counting fence used in Newfoundland salmon rivers.

9 feet 3 inches, and height 10 feet 3 inches. It is built in sections using 2- by 4-inch lumber for the framework, and assembled by bolting the sections together with galvanized carriage bolts. A funnel the full height of the trap tapers from 5 feet to 1 foot, and extends into the trap 6 feet. Wire screens are fitted between uprights of the framework to give a flush surface on the inside. This is an improvement over earlier types where screens were fastened to the outside of the framework, thus making the inside surface irregular. The screen frames (4 feet 8½ inches by 3 feet) are made of 1¾- by 1¾-inch lumber, and are covered with 16 gauge, galvanized steel wire cloth. The screens are fastened to the uprights of the trap with sash screws, and are arranged in two tiers all the way around the trap so that at low water the top tier can be removed for greater convenience in working. 1-inch-square mesh is used in the salmon trap screens, ½-inch in the smolt trap screens, and ¼-inch in the trap bottoms.

Ballast pounds on both sides of the trap are supported by projecting floor joists. The pounds extend the full length of the trap, and are 2 feet wide and 4 feet high. The entire side of the pound is hinged at

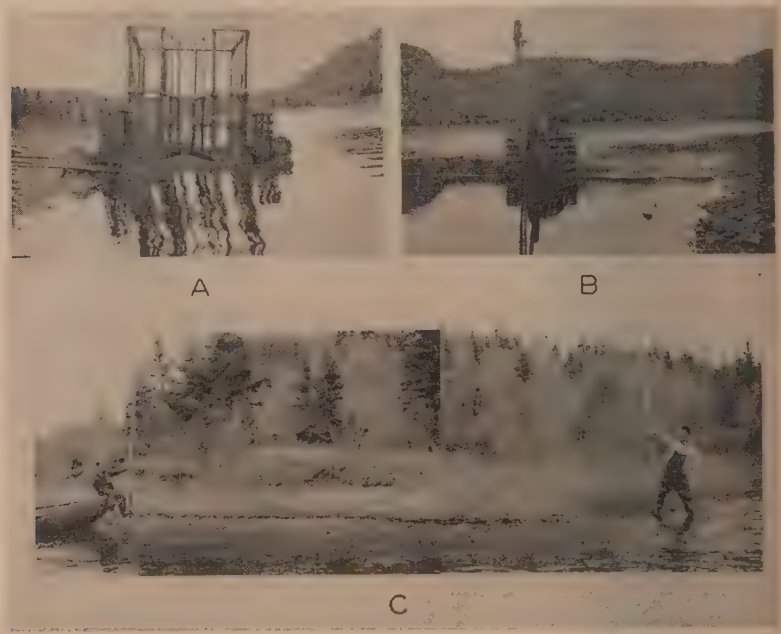

FIGURE 3. A — Trap being launched; B — Part of fence showing pier at low water; C — Net section complete with pole at each end and chain lashed to foot rope.

the top and fastened at the bottom with sliding bolts which have wires attached running to the top of the trap. When the trap is to be removed from the water the pounds can be readily emptied by pulling on the wires. The bottom of the pound slopes away from the trap so there is little difficulty in getting all the rocks to slide out into the river.

Fish are removed from the trap by way of an elevator pound which is situated at the upstream end of the salmon trap and at the downstream end of the smolt trap. The pound is 9 feet 11 inches high, 3 feet 10 inches long, and 3 feet wide. Between the pound and the trap is a vertically sliding gate. An elevator of angle iron frame with a bottom of fine mesh netting is fitted into the pound so that fish cannot escape but yet is free to move up and down. It is raised by means of a 4-inch block and tackle, and lowered by the weight of the iron frame when released.

Piers

These are crib structures filled with rock (Figure 3B). Triangular in shape, they have equal sides 6 feet long and various heights depending on the depth of water. It is not necessary to have them the full height of the water. For example, on Bay du Nord River piers 6 feet high were quite satisfactory in 9 feet of water. The bottom of the pier is made of sticks, around 3 inches in diameter, spiked to two logs which are approximately 8 inches in diameter. The logs in the walls average around 5 inches in diameter. The upstream corner is covered with 1-inch boards to prevent the netting from catching up on the ends of the logs. The upright pole at the upstream end, which supports the suspension cable, is from 6 to 8 inches in diameter, and its height depends on the depth of the water.

Suspension Cable and Anchorage

The type of cable was recommended by Canada Wire and Cable Company Ltd. It is referred to as 6 by 7 galvanized plow steel wire rope with fiber center. This means that it is made up of six strands around a fiber core with seven wires in a strand. It is well qualified to withstand abrasion, but it is not so flexible as types with a greater number of wires. The size of wire used is 7/16 inches in diameter which has a breaking strength of 8.5 short tons.

Anchorage is provided by embedding an 80-pound anchor in the bank and cross spiking with stakes to prevent slipping. A large, solid tree is also used if one is available in the spot where it is needed. Trees have been used as often as anchors.

Net Sections

All the sections (Figure 3C) are 40 feet long but vary in depth from 15 to 20 feet for the smolt fence and from 12 to 18 feet for the salmon fence. The smolt sections are made of 9-thread tarred cotton

twine, 1-inch stretched mesh, and the salmon sections of 12-thread tarred cotton, 2-inch stretched mesh. Head and foot ropes are 6-thread Manila rope. The twine has as little gathering as possible because the more open the meshes, the greater the amount of dirt which can pass through.

The nets as they came from the factory are prepared on the job by attaching a small pole to each end of the net and ½- to ¾-inch chain to the foot rope. Floats are not needed because the head rope is fastened to the suspension cable. Marline is used to lash the poles and chain to the net. The foot rope is fastened a few inches from the bottom end of the pole so that the foot rope will rest on the bottom when the pole is driven into the bottom. When the skirt line is lashed to the pole, any surplus netting is gathered near the bottom. This slack netting at the bottom helps to keep the foot rope on the bottom.

Chain is very satisfactory for sinkers because it keeps the whole foot rope tight to the bottom and does not get tangled in the netting when being handled. Any old chain is suitable provided it is the right size. Chain less than one-half inch is not heavy enough and over three-quarter inch, although excellent for retaining nets on bottom, is rather heavy for pulling into small boats.

The rule followed in determining the depth of net sections is to double the known or expected depth of water where they will be used. This provides sufficient bag so there is not too much strain on the twine and the foot rope does not lift.

Installation

The trap is assembled on the bank of the river upstream from the location chosen for the fence. Three logs are bolted to the floor of the trap so that it will not be damaged when it is being pushed into the river on skid logs. Empty oil drums lashed to the sides of the trap keep it afloat while it is being towed to the required position with two 14-foot, outboard boats. The trap is temporarily held in position by means of two anchors which are sometimes left all season as an additional aid in holding the trap in place. When the drums are removed, rock from the two boats is simultaneously dumped into the ballast pounds on the sides of the trap until it rests securely on the bottom. A second trap is similarly placed in the river beside the first.

To indicate positions for piers, markers are tied every 35 feet on a small rope stretched from the trap to the anchor on the river bank. The piers, which are built on the river bank, are floated into position in the same manner as described for the traps. A large pole is driven into the bottom at the upstream end of each pier and spiked to it. A platform is built on one of the boats so that a man can stand on it to drive the poles with a large maul. A hardwood bracket for supporting the cable is nailed to each pole so that it is level with the top of the trap. The cable which has two 12-inch turnbuckles at each end is fastened

to the distant corner post of the trap, placed in the brackets, and held taut at the shore end with block and tackle while it is being secured to the anchor with turnbuckles and anchor shackle. When the cables on the four arms have been installed, they are tightened by means of the turnbuckles just enough to take out the sag.

The 40-foot net sections are next placed between the piers. One end pole is driven into the bottom and tied to the pier pole. The boat is pulled towards the next pier and the headrope of the net is tied to the cable at intervals of 2 to 3 feet. Nets are set with the current, and three men are usually required. Four, however, make an ideal crew especially during periods of high water when two boats are often needed. At such times the current is so strong difficulty is experienced in keeping the second net pole in place while it is being tied to the pier pole. The operation is quite simple if two additional men are available to pull on a rope attached to the end of the net from a second boat moored a few feet away from the pier.

Operation

Fish Handling

Two floats are used, one at the downstream end of the traps for handling smolts and one at the upstream end for salmon. The float consists of a wood floor, 8 feet by 10 feet, resting on four empty oil drums, with a framework of small poles covered on top with a tarpaulin or tent fly for protection from sun and rain. A work table is placed in the center of the float and an anaesthetizing tank on the side next to the elevator. The tank is 3 feet square, 2½ feet deep, made of waterproof canvas, and suspended from poles to keep the sides upright. A recovery cage (8 by 3 by 3 feet) placed in the river beside the float has a wood frame covered with wire cloth.

In counting and marking operations a number of smolts are driven into the elevator pound, the door is closed, and the elevator is raised to the surface. They are dipped from here into the anaesthetizing tank using a small dip net made of cloth on a wire frame padded to prevent injury. One at a time the anaesthetized smolts are transferred to the table for tagging, fin clipping, and measuring, and then released into the recovery cage. When all the smolts in the trap have been handled in this way, the recovery cage is tipped on its side and the smolts are free to continue downstream. In salmon clearing operations only one or two at a time are allowed to enter the elevator pound. The salmon elevator is fitted with a false bottom, and when the elevator is raised to the surface, this false bottom is tilted so that the salmon rolls into the anaesthetizing tank.

The anaesthetic is urethane, ethyl carbamate, which is used at the rate of 1 pound to 20 imperial gallons of water. Both water and urethane are added as required and the whole mixture renewed occasionally. Five to

six pounds of urethane per year were used on Bay du Nord River.

Care of Nets

The nets are inspected for breaks in the twine and cleaned at least once a day. Logs and branches are removed by hand, but a large dip net has been found to be very effective for removing small fragments such as leaves and grass. The iron hoop of the dip net is covered with canvas so as not to damage the netting. If a section of net becomes very dirty, which often happens during flood conditions, it is removed and a clean section put in its place. Most of the sections have to be changed several times a month to make minor repairs. At least once a month all sections are changed, washed, and dried to prolong the life of the netting. In changing sections the new section is always placed in position on the upstream side of the fence before removing the old section from the downstream side.

Tarred cotton netting is very satisfactory. The same netting has been used for two seasons on Bay du Nord River where the length of ths smolt season is 2½ months and the salmon season 5 months. At the end of the season the netting is tarred in a mixture of 3 imperial gallons of pine tar and 20 gallons of kerosene. The mixture is boiled until all the tar is completely dissolved. Almost continuous stirring is necessary as the oil is brought to a boil. The boiled mixture is poured into a tank and the netting dipped in it. The netting is then put on poles over another tank to drain for a few hours and afterwards spread to dry. The recovered mixture can be used again. All netting should be well dried before storing for the winter.

River Traffic

On Gander and Bay du Nord Rivers it was necessary to provide a passage in the fence for canoes and small boats. This was done by lowering the head rope of one section to the surface of the water and attaching a small pole to each side of it. This kept the head rope on the surface and also prevented damage to the net by boats when passing over it. When salmon were running, the head rope was raised out of the water at night because boats were not on the move after dark.

During the 1954 season 550 saw logs were passed over the lowered section of the fence on Bay du Nord River without any difficulty. The logs were held in a boom a short distance above the fence and around 25 at a time were hitched together in a raft and towed by motor boat to the lowered section of the fence which was depressed a few inches below the surface while the boat and raft of logs drifted past.

Acknowledgments

Many of the salmon personnel in Newfoundland have contributed to the design and methods of installation and operation of this counting fence. Fred A. Day,

who was in charge of fence operations, and Alex P. Cowan, who relieved him at times, were also most helpful in preparation of the paper. Temporary assistants in the field had experience in commercial fishing and their knowledge of nets was invaluable.

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EFFECT OF FOREST SPRAYING WITH DDT ON AQUATIC INSECTS OF SALMON STREAMS

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rinted from Volume 86 (1956), Transactions of the American Fisheries Society.
Published 1957. Printed in U.S.A.

FRB 4-3

EFFECT OF FOREST SPRAYING WITH DDT ON AQUATIC INSECTS OF SALMON STREAMS

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Abstract

Number and volume of aquatic insects emerging from tributaries of the Miramichi River of northern New Brunswick, where forest-covered watersheds had been sprayed from the air with 0.5 pounds of DDT per acre, are compared with insect emergence from unsprayed streams. Adult insects were captured as they emerged from the water in yard-square cage-traps. In the streams affected by DDT fewer kinds of insects, particularly of the larger species such as caddisflies, were found. The sprayed streams had, generally, larger numbers than the unsprayed but in all sprayed streams the volume represented was significantly lower because of the relative scarcity of the larger forms. The insect fauna of the sprayed streams was found to be deficient in the kinds of insects on which the salmon were mainly feeding in the unsprayed streams.

Early in the summer of 1954, an extensive forest area in the northe part of the province of New Brunswick was sprayed to control a serio outbreak of the spruce budworm, *Choristoneura fumiferana* (Clem.). 1956, as the epidemic spread, other areas in the same general regic were sprayed. DDT in oil was applied from aircraft at the rate of 0 pounds of DDT per acre.

As a result of the spraying in 1954, many young Atlantic salmo *Salmo salar* L., were killed in the Miramichi River system, one of th better salmon streams of the Maritime Provinces. An examination w made of the bottom fauna about a month after the spraying and in th most affected parts no aquatic insects were observed. Sections of the sam river outside the spray area were found at this time to have an abundan and varied fauna. During the spraying, collections were made of man individuals of the larger and more conspicuous species of aquatic insec that were found dead. These are species which, if their life cycles ha not been interrupted, should have been in evidence when the stream were examined later in the summer. They were found in the unsprayed parts of the river at this time.

Therefore, as part of their programme of research on the Atlanti salmon, the Fisheries Research Board of Canada decided to investigat the effect of the spraying on the aquatic insects. The Northwest Mira michi River was selected as the locus of the work with headquarters i a small field laboratory at Curventon, Northumberland County. The con dition of the fauna has been followed through the summers of 195 and 1956. In the former the field work and preliminary analysis of dat

s carried out by D. A. Hurley and in the latter by J. Malia, student stants. Dr. J. L. Hart, director of the Biological Station at St. Andrews, B., Dr. C. J. Kerswill, in charge of Atlantic salmon investigations l other members of the staff of the station provided facilities and gave neral supervision.

Use and Location of Insect Cage-Traps

For the 1955 programme four tributaries of the Northwest Miramichi er were selected. Two of these, the North Branch of the Big Sevogle l one of its small tributaries, were examined at points more than five es within the spray boundary. The other two, Millstream Brook and out Brook, were more than five miles outside the spray boundary. This angement minimized the possibility of contamination of the controls spray and also mitigated against the re-establishment of insects in the ayed streams by immigration from unsprayed ones. The emerging in- ts were sampled by means of cage-traps, two of which were placed nacently in rapids at each location. Those in the North Branch of the g Sevogle and those in the Millstream Brook were placed approximately teen miles downstream from their sources. The cage-traps were placed Trout Brook and the small tributary of the Sevogle River at approxi- tely nine miles and one mile respectively from their sources. The Mill- eam Brook and the Big Sevogle River were similar in size, rate of flow, pe of bottom and in thermal conditions at the study stations. The other o streams were smaller and colder, the small tributary of the Sevogle ver being the coldest. The 1955 collections gave a basis for comparing insect populations of streams a year after they had been sprayed with DT with the insect populations in the two control streams which had t been sprayed at any time.

In 1956 the watershed of the North Branch of the Big Sevogle River s not sprayed, thus affording an opportunity to study the fauna of uatic insects in the second year following spraying. Trout Brook was ayed for the first time in that year and this gave an opportunity to aluate the effect of the spray on the insects in the year of spraying. he Millstream Brook was not sprayed in 1956 and so remained as a ntrol. The locations of the cage-traps in the Big Sevogle River, Trout ook and Millstream Brook were approximately the same in 1956 as in 55 but the small tributary of the Big Sevogle was not examined in 1956. ree cage-traps were placed in each of the three continuing stations in 56 instead of two as in 1955.

The cage-traps are a yard square and are designed to catch and retain insects which emerge from the surface of the water of the rapids (Ide, 40). In order to insure that the traps would retain the smaller insects ee sides and the top were covered with a glazed wire screening, "win- wlite," and the fourth side with 25 mesh copper screening rather than ng entirely of 15 mesh as specified in the original description. The

cage-traps were emptied at approximately 24-hour intervals and the co lections analyzed for the kinds, numbers and total volumes of insects. Th collections began in the first week of June and ran until the first wee of September. During this period collections were made on five da of each week in 1956 with the exception of one daily collection for eig cages and two daily collections for one cage which were missed. In 19 several daily collections were missed from all cages owing to freshets, pa ticularly in the early summer. The fact that six daily collections we generally taken each week compensated for these losses.

The emergence of insects into the cages at the different stations w compared on a sixty day basis although the number of daily collectio from different cage-traps varied from 58 to 70 for the season.

Insect Emergence from Sprayed and Unsprayed Streams

The results will be presented under three headings:

(1) Effect of the spray on the aquatic insects in the year of sprayin (2) effect of the spray on the aquatic insects in the year following spra ing and (3) effect of the spray on the aquatic insects in the second ye following spraying.

Emergence of Aquatic Insects in the Year of Spraying

Trout Brook was the only stream of the sample series which was spraye in 1956, the same year in which its insect fauna was studied. Figure shows the change in the average number and corresponding volume o insects emerging daily into the three cage-traps used in sampling at th station. The spray was applied June 14 to 17. Before this period th number of insects emerging was not large but the corresponding volum was relatively high. In the three weeks following the spraying the emer gence of insects was almost negligible. From the middle of July to th middle of August there was, however, a great increase in the number o insects emerging but it is evident from a comparison of the peak of th number curve (B) with the corresponding peak of the volume curve (A that most of the insects were small. There were large numbers of minut chironomids which have little bulk. The sharp rise in the curve of volum at this time can be attributed mostly to caddisflies, larger insects, whic emerged during the second and third weeks of July and may have bee in the pre-pupal or pupal stage when the spraying was done. In Figure are the corresponding volume (A) and number (B) curves of emergin insects taken from Trout Brook in 1955, the year before it was sprayed The ratio of volume to number illustrated by these two latter curves an in comparison with the curves of Figure 1 indicates that the insects emerg ing were fewer but on the average of larger size in 1955 than in 1956 Table 1 gives a further comparison of kinds and quantity of insects emerg ing at this station in the two years. In Table 1 the emergence of insect

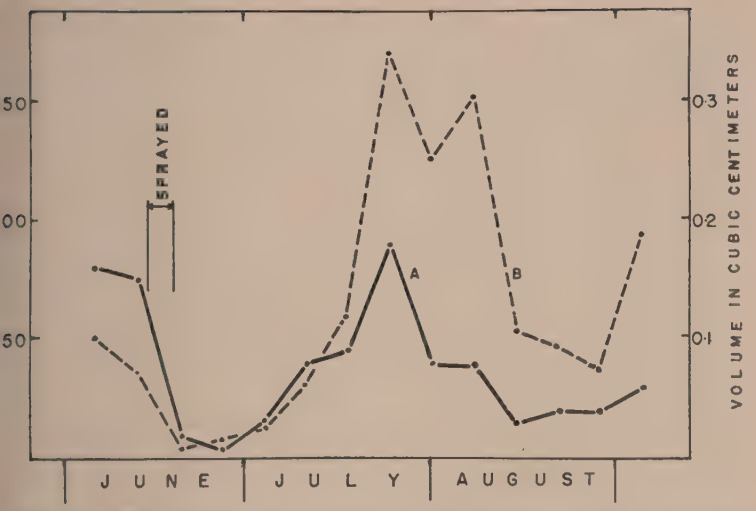

FIGURE 1. Weekly change in number (B) and volume (A) of insects emerging ly into three yard-square cage-traps in Trout Brook in 1956, the year in which stream was sprayed. Each weekly point is the average of five square-yard 24-hour lections.

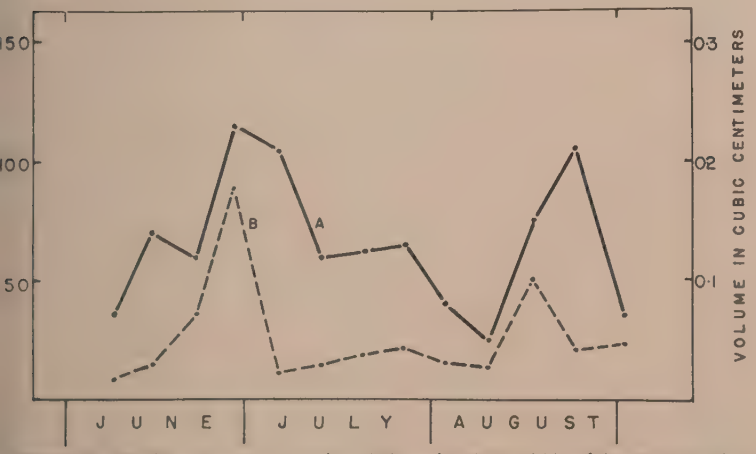

FIGURE 2. Weekly change in number (B) and volume (A) of insects emerging ly into two yard-square cage traps in Trout Brook in 1955, the year before spraying had been done in the area. Each weekly point is the average of from r to six square-yard 24-hour collections.

after June 15 in both years is compared on a 60-day basis. Althou the number emerging in each cage in 1955 was lower than in 1956 t corresponding volumes were higher in the former year and the inse were of larger size on the average as shown by the ratio of volume corresponding total number in the last column.

Emergence of Aquatic Insects in the Year Following Spraying

The programme of 1955 was designed to find out the effect of spr on the insects in the North Branch of the Big Sevogle River and small tributary both of which were sprayed in 1954. The results ha been reported on earlier (Kerswill 1956, Hurley 1956). The cages the Big Sevogle produced less than half the bulk of insects produced the cages in the Millstream Brook control stream. The insects in t former were small species giving an average size of about one half th of the control. The relatively large number of chironomids was instr mental in determining this size relation. The small tributary of the Sevog which was also sprayed was not as drastically affected as was the ma river. Three species of caddisflies were represented in the collections fro its cages as compared to none in those of the Big Sevogle. In both, ho ever, there were significant qualitative differences between the faunas the sprayed streams and their corresponding controls as shown in Table

Table 1. *Numbers and volume of insects emerging into yard-square cage-tra in Trout Brook from June 15 to September in 1956 and 1955. Trout Brook u sprayed for the first time June 14 to June 17, 1956. All figures are for 60 days.*

Year of Sampling	Cage-trap number	Percentage Number						Total Number	Volume in cubic centimeters	Volume in cubic centimeters / Total number
					Diptera					
		Plecoptera	Ephemeroptera	Trichoptera	Simulidae	Chironomidae	Miscellaneous			
1955	TV	5.6	11.9	10.6	2.7	66.4	2.8	1493	5.1	0.0034
	TVI	3.3	23.4	15.5	3.9	51.6	2.3	1604	8.2	0.0051
1956	TI	0.9	1.3	3.4	0.1	89.6	4.7	3638	4.1	0.0011
	TII	0.5	0.7	1.4	0.0	95.0	2.5	3973	3.2	0.0008
	TIII	0.6	1.2	2.1	0.2	95.7	0.2	4337	3.5	0.0008

ıERGENCE OF INSECTS IN THE CONd YEAR AFTER SPRAYING

In 1956, the second year after the Sevogle area had been sprayed, daily nples of aquatic insects were again collected from the stations in the ɔrth Branch of the Big Sevogle. These were compared with those from llstream Brook which served again as a control. Table 2 shows this mparison. For 1956 the volumes of aquatic insects taken by all cages the Sevogle series were less than those of the control cages in Millstream ook although the two highest numbers of insects per cage were taken two of the Sevogle cages. The ratio of volume to total number in each ge-trap also shows that fewer individuals of species of larger size were resented at the Sevogle than at the Millstream. The percentage repre-ıtation of the different groups of insects as shown in Table 2 throws rther light on this relationship. All but about one thousand of the ects from trap SIII in the Sevogle River were chironomids. The chirono-ds taken in the survey were mostly minute species of the subfamily thocladiinae, in general under three millimeters in length. It was esti-ıted that the 13.5 thousand chironomids taken in this trap gave the ne bulk as the remaining thousand which were mainly Ephemeroptera d Plecoptera, all of moderate size. Large Plecoptera were taken ly in the Millstream Brook. Some of these were as much as an ch and a half in length and contributed greatly to the bulk of insects ken in samples there. The Trichoptera were in insignificant numbers at e Sevogle, although they formed a significant component of the fauna the Millstream. Two caddisflies of a species characteristic of slowly owing water and five microcaddisflies were the only caddis to emerge om the 27 square feet of rapids in the Sevogle covered by the cage-ips during the 70 days of sampling in 1956. None was taken from e 18 square feet of the same rapid sampled in 1955. In contrast 143, 172 d 146 were taken in the three cage-traps of the Millstream Brook series 1956. Since several species of Trichoptera which had been killed by e spraying of that year were found at the Sevogle station in 1954, it concluded that this group of insects was almost eliminated from this tion of the stream by the spray and in the second year following spray-g had not reappeared to any appreciable extent. This decrease in num-ers of Trichoptera, which are mainly predatory, may account for the creased abundance of small insects, mainly chironomids, on which they dinarily feed.

EFFECT OF DDT ON STREAM INVERTEBRATES

The effect of DDT on invertebrates of streams has been investigated ainly in relation to three operations: (1) forest pest control (2) experi-ental treatment to evaluate the effect on fish and their food and (3) ack fly control. The present investigation fits into the first category. ne method of applying the DDT in these three operations has been to ray from aircraft with a solution of the insecticide in oil. Results ob-

tained by this method are of most interest in the present discussion. Resul obtained by other methods are also relevant when these methods gi concentrations of the poison in the water comparable to those obtain by aerial spraying.

The development of methods for applying the insecticide has led gra ually to the adoption of fairly standard procedures. Pertinent literatu includes Hoffman and Merkel (1948), Hoffman and Surber (1949), Hof man and Linduska (1949), Brown (1951), Kerswill (1956) and Hurl (1956) dealing more particularly with forest operations, Hoffman ar Surber (1945), and Savage (1949) dealing with experimental applic tions to streams and Arnason *et al* (1949), Brown (1951) and Jamnba and Collins (1955), on black fly control. In addition, testing of t toxicity of DDT formulations to various forms of stream life has bee carried out in the laboratory as is reported by Eide *et al.* (1945), Gjuli *et al.* (1949) and Savage (1949).

Aerial spraying of approximately one pound of DDT per acre has bee adopted as a satisfactory dosage for control of many forest pests but dosage of 0.1 pound per acre or less has been adopted for black fly contro

TABLE 2. *Number and volume of insects emerging into yard-square cage-tra in the North Branch of the Big Sevogle River (SIII-SV) and into cage-traps the Millstream Brook (MI-III) from early June to early September in 1956. A figures are for 60 days.*

	Year of Sampling	Cage-trap number	Percentage Numbers						Total number	Volume in cubic centimeters	Volume in cubic centimeters Total number
			Plecoptera	Ephemeroptera	Trichoptera	Diptera					
						Simuliidae	Chironomidae	Miscellaneous			
Sevogle River Sprayed in 1954	1956	SIII	1.5	4.1	0.0	0.8	93.5	0.1	14505	8.4	0.000
		SIV	1.9	8.0	0.0	1.9	87.5	0.7	7330	6.3	0.000
		SV	1.7	13.9	0.0	3.4	75.4	5.6	4422	5.5	0.001
Millstream Brook Unsprayed	1956	MI	8.6	9.6	4.2	0.3	74.8	2.5	3418	11.2	0.003
		MII	12.6	11.4	4.9	1.1	67.2	2.8	3526	11.2	0.003
		MIII	7.7	8.9	3.0	0.8	77.7	1.9	4874	13.6	0.002

TABLE 3. *Approximate number[1] of species in the orders Plecoptera Ephemeroptera and Trichoptera which were identified in collections of 1955 from one cage-up at each location in four streams.*

Order	Category (Genus, Family or Sub-family)	Approximate Number of Species			
		Sprayed Streams		Control Streams	
		SI	SIV	TVI	MVII
Plecoptera (Stoneflies)	Acroneuria	0	0	1	2
	Isogenus	0	1	0	1
	Isoperla	1	1	1	1
	Alloperla	2	2	2	1
	Leuctra	2	2	2	1
	Nemoura	1	1	1	1
	Total	6	7	7	7
Ephemeroptera (Mayflies)	Ephemerella	3	4	5	5
	Paraleptophlebia	1	1	2	2
	Baetis	0	1	4	5
	Pseudocloeon	0	1	2	2
	Heptagenia	0	1	1	1
	Iron	1	2	2	1
	Rhithrogena	0	0	1	0
	Total	5	10	17	16
Trichoptera (Caddisflies)	Rhyacophilidae	1	0	7	6
	Philopotamidae	1	0	1	1
	Psychomyidae	0	0	1	1
	Hydropsychidae	1	0	3	3
	Hydroptilidae	0	0	1	0
	Leptoceridae	0	0	1	1
	Lepidostomatidae	0	0	2	1
	Helicopsychidae	0	0	1	1
	Brachycentridae	0	0	0	1
	Limnephilidae	0	0	1	1
	Total	3	0	18	16
	Grand Total	14	17	42	39

[1] most species were distinguished but some closely related ones were identified to species group only. This was more frequently done for the more complex genera of the controls so that the numbers for these are probably disproportionately low.

The former concentration gives good control of many forest pests and it is claimed that it does little lasting damage to other elements of the fauna of the forest (Hoffman and Linduska, 1949). The latter dosage gives good control of the susceptible larvae of the black flies without seriously affecting the other stream arthropods (Jamnback and Collins, 1955). For both operations evidence has been advanced which indicates that dosages lighter than standard were ineffective in bringing about control of the pest and that dosages heavier than standard resulted in elimination of some important components of the fauna.

It follows therefore, that, because of the heavier dosages employed forest spraying, this operation rather than black fly control measures pr sents the greatest danger to the life in streams. The dosage reaching stream in a forest spraying operation would be considered a serious ove dosing in a black fly control operation.

In the forest spraying of a watershed there is danger under certa weather conditions that heavy concentrations of the insecticide may rea the streams in runoff. This danger is not present in black fly contr operations where only the stream is sprayed.

In the New Brunswick forest spraying already considered, the dosa has been 0.5 pounds of DDT per acre, half the "optimal" amount referred to above. Nevertheless the resulting differences between the fau of aquatic insects in sprayed and unsprayed streams was pronounced. Th conclusion that these differences are a result of the DDT is supporte by similar results reported in the literature. It has been shown by th experiments of several workers including Eide *et al.* (1945), Gjul *et al.* (1949) and Savage (1949) that concentrations of DDT which r sult from such sprayings are highly toxic to many kinds of aquatic inse and other organisms. Savage (1949) found that the insect mortality w caused by the DDT and not the oil solvent. The data presented sho marked difference between the pre- and post-spray fauna of Trout Bro (Figures 1 and 2 and Table 1) and the fauna of the North Branch the Big Sevogle River the year following spraying and the fauna Millstream Brook, a control stream of similar character. In the second ye after spraying even more pronounced differences between the fauna these latter two streams were found, as illustrated in Table 2, and th big differences were in the quantity of insects that emerged, especial when bulk, rather than number, is the criterion of quantity. Pronounce qualitative differences in the fauna of the sprayed and unsprayed strean were also found and are illustrated in Table 3. The small number species surviving in the sprayed streams contrasts with the larger numb in the unsprayed. Some of the species which were absent from the Nort Branch of the Big Sevogle River and present in the Millstream Brook 1955 were collected dead from the former at the time of spraying in 195 which is strong evidence that they were eliminated by the spraying.

In 1956, the second year after spraying, the fauna at the Sevog Station was little changed qualitatively from 1955 but the proportion representation of the insect groups had altered. The total number of in dividuals emerging at this location was also greater in 1956 than in 195 The number emerging into two of these cages in 1956 was greater tha the emergence into any of the Millstream Brook controls. Howeve despite the large numbers, smaller volumes, ranging from a little le than one-half to slightly more than two-thirds those of the correspondin controls, were taken in 1956 as shown in Table 2. Similarly the popul tion of the Trout Brook was numerically higher but volumetrically low

1956, the year of spraying, than in 1955 as Table 1 shows. From the ve it seems evident that the spraying had been selective in its action, minating many species, but that there were many species which sur- ed. Of those which survived, the small species, particularly chironomids reased prodigiously and were present in greater numbers even in the year spraying than in normal years. This increase is attributed to short life les and fewer predators and competitors. The sprayed streams were in production of bulk of insects as compared with their controls in years following spraying in spite of larger numbers of insects emerging most of their cage-traps.

The population which developed after spraying was qualitatively dif- ent from the pre-spray population. Small chironomids were dispro- rtionately abundant and larger forms scarce. The bulk of insects re- ained relatively low in the sprayed streams and this observation finds le confirmation in the papers cited. Possibly this is because of difference sampling methods used. The usual apparatus for sampling bottom na of rapids is the Surber sampler (Surber, 1937) or modifications it, the best known of which is that described by Hess (1941). Both square-foot samplers operated so as to collect aquatic invertebrates m the enclosed area of bottom. The resulting catch gives a measure the "standing bottom crop" and may be expressed as number or volume weight of organisms. Such a sampler is particularly suitable for obtain- the total volume or weight since loss of some small individuals, which inevitable, does not introduce a large percentage error in the result. e sampler is adequate when used, as it was by Surber, to measure the antity of fish food organisms on the bottom. When, however, the mple is to be expressed as number of individuals, a serious error may ult and this error increases with increase in numbers of small animals the population. In using this sampling technique or others which in- lve picking over the bottom the author has found that the larger ertebrates are taken but that small species or the young of larger ecies are poorly represented in the sample. This happens even when is known from subsequent collections made of emerging adults that vae were numerous at the time the bottom sample was taken, Ide (1940).

The cage-trap method has drawbacks but would seem to be particularly icient for taking adults of the small insects, including chironomids, ck flies and empids, which are proportional to and more nearly repre- ntative of the population on the bottom than are samples taken by other thods. The cage-traps cover a large area and thus a large sample of emerging insects is obtained. It is not feasible, however, to operate ny such traps and therefore the method does not lend itself to extended mpling of surveys. As a research technique it may however provide formation which would be of value in interpreting samples taken by her means.

The large number of chironomids and the almost complete absence of

caddisflies are the most conspicuous features of the sprayed streams ex amined in the present investigation. Davies (1950) has reported on phenomenal increase in black flies in a stream in the years followin DDT treatment. The stream had been sprayed in 1944 from a helicopte with DDT at a rate of six pounds of DDT per acre. Using cage-trap Davies had sampled the populations of emerging black flies from 193 to 1947. Although almost no black flies emerged in the year that th stream was sprayed the emergence increased in the years thereafter unt over 80,000 emerged from a square yard during the summer of 194 which was about seventeen times the average emergence of the five pr spray years. These small flies were the dominant group in this strea after spraying.

Th more serious effects of spraying on the fauna from the standpoin of the fish would appear to be the reduction in bulk of fish food and th high proportion of this lessened bulk which is made up of insects whic are so small as to be unsatisfactory for the larger young salmon. As muc as half the volume of the aquatic insect food of the sprayed streams ha been estimated to be these minute insects, leaving only a small quantit of insects which may be more readily utilized. Qualitative changes i the insect populations are significant as it has been shown by Allen (1941 and the present author (1942) that the salmon and trout which ar characteristically insectivorous in their younger stages utilize some kind of insects more than others, depending on availability. Caddisflies ar very frequent in the stomach contents of both salmon and trout.

Another and perhaps the most serious consequence of the spraying i that many of the insects which were eliminated have not become re established even in the second year after spraying. Many of these aquati insects do not disperse widely and consequently it may be many year before they will be rehabilitated by natural means. In the meantime th fish feed on other organisms, not normally utilized, which persist in th stream after spraying. Hurley (1956) found, for instance, that th salmon fingerlings in the dirth of aquatic insects of suitable kinds fe largely on snails.

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MARINE FISH MUSCLE NUCLEIC ACIDS[1]

H. M. Bluhm and H. L. A. Tarr

Abstract

The muscles of six species of North Pacific ocean fish contained from 42 to 142 μg. per 100 mg. wet weight of ribonucleic acid (RNA) and from 0.2 to 2.5 μg. per 100 mg. of deoxyribonucleic acid (DNA). The molar ratio of purine and pyrimidine bases in lingcod and sockeye salmon muscle RNA was: adenine, 1.0; guanine, 2.0; cytosine, 1.0; and uracil, 1.25. Chemical analysis of isolated lingcod muscle RNA indicated that it was a comparatively pure product and was free, or practically free, from protein and amino acids.

Introduction

The occurrence of free ribose in fish muscles stored at 0° C. for several days *post mortem* was first demonstrated in this laboratory (10), and the role of riboside hydrolase enzymes in its formation was established later (11, 12). During these investigations it was observed that alcoholic extracts of *post rigor* marine fish muscles contained significant quantities of ribonucleosides which were not evident in muscles of freshly killed fish. The present paper records the quantitative distribution of RNA and DNA in the muscles of six species of North Pacific ocean fish, and describes the isolation and chemical characterization of RNA from sockeye salmon and from lingcod.

Materials and Methods

Whole small fish, or pieces of excised muscle from larger fish, were frozen in an insulated box containing crushed solid carbon dioxide as soon after capture as possible and normally while the fish were still alive. The samples were wrapped in polyethylene and stored at −25° C. until they could be used conveniently.

While still frozen, samples of the muscles were homogenized in cold 70% ethanol and fractionated by the method of Ogur and Rosen (6). Quantitative determinations of the ribose (5) and deoxyribose (8) content of the appropriate fractions were made, and the RNA and DNA content of the tissues were calculated from these results. After several attempts to extract RNA from the frozen muscle samples by available methods it was found that only that of Volkin and Carter (14) yielded desirable products. The actual yields of RNA by this technique were, as stated by the above authors, comparatively poor, amounting to only 20–25% of the calculated RNA content of the muscles. However, when freeze-dried from aqueous solution, the sodium RNA was obtained as a fluffy, white, completely water-soluble product of high purity (see below).

For determination of the purine and pyrimidine base content the RNA samples were hydrolyzed 1 hour at 100° in 70% perchloric acid (Wyatt (15)). The free bases were separated by quantitative paper chromatography using

[1]Manuscript received May 13, 1957.
Contribution from the Fisheries Research Board of Canada, Technological Station, Vancouver 2, B.C.

isopropanol:HCl:H_2O solvent (15) in 16-hour ascending development at room temperature. The compounds were located on the air-dried chromatograms with a "Mineralite" ultraviolet lamp, and their concentrations determined by elution with 0.1 *N* HCl for 18 hours at room temperature and application of the differential ultraviolet spectrophotometric method of Vischer and Chargaff (13) to the eluates. The nitrogen content of purified lingcod RNA was determined by the micro-Kjeldahl procedure and the phosphorus content by the method of Fiske and Subbarow (1). A quantitative biuret test (3) of the lingcod RNA and chromatography of its acid hydrolyzates (7) were employed in attempts to demonstrate the presence of protein and amino acids in the respective materials.

Results and Discussion

The RNA content of the fish muscles examined (Table I) was somewhat lower than that which has been reported for certain normal mammalian muscles (4), but the manner in which the samples were secured may have permitted some degradation. The DNA content was considerably below that which has been reported for mammalian skeletal muscles (4).

The molar ratio of purine and pyrimidine bases of the RNA prepared from lingcod and sockeye salmon muscles (Table II) was practically identical, being approximately as follows: adenine, 1.0; guanine, 2.0; cytosine, 1.0; and uracil, 1.25. The rather high guanine content is in keeping with results obtained with the RNA from carp muscle nucleotropomyosin (2). However, the cytosine content was considerably higher, and the uracil content somewhat lower, in the latter preparation, in which the molar ratio of the bases was as follows: adenine, 1.0; guanine, 2.1; cytosine, 1.85; and uracil, 1.1.

TABLE I

NUCLEIC ACID CONTENT OF FISH MUSCLES (μG./100 MG. WET WEIGHT)

	RNA	DNA
Sockeye salmon (*Oncorhynchus nerka*)	100	2.5
Spring salmon (*Oncorhynchus tschawytscha*)	142	1.4
Pink salmon (*Oncorhynchus gorbuscha*)	42	0.2
Coho salmon (*Oncorhynchus kisutch*)	123	1.5
Lingcod (*Ophiodon elongatus*)	47.3	1.0
Starry flounder (*Platichtys stellatus*)	58.0	2.0

TABLE II

MOLAR RATIO OF PURINE AND PYRIMIDINE BASES IN FISH MUSCLE RNA

	Sockeye salmon	Lingcod
Adenine	1.0	1.0
Guanine	1.95	2.3
Cytosine	1.08	0.97
Uracil	1.23	1.27

The results of detailed chemical analysis of lingcod RNA are recorded in Table III. The ratio of purines to pyrimidines is somewhat higher, and of nitrogen to phosphorus somewhat lower, than has been recorded for yeast RNA (9). Neither protein nor chloride could be detected in the preparation, and only minute traces of amino acids other than glycine, which is derived from acid hydrolyzed purines, were found in treated (7) preparations.

TABLE III

Composition of lingcod sodium RNA

	μg./mg.	μM./mg.		μg./mg.	μM./mg.
Adenine	65.1	0.481	Chloride	Negative	
Guanine	168.6	1.115	Biuret	Negative	
Cytosine	52.3	0.471	Amino acids	Slight traces on hydrolysis	
Uracil	68.6	0.612	N/P ratio	1.68	
Purines	234.0	1.59	Purine/pentose	1.04	Theory 1.0
Purine bound ribose	228.0	1.52	Bases/phosphorus	0.94	" 1.0
Total bases	355.0	2.679	Base N/total N	1.01	" 1.0
Phosphorus	89.0	2.87	Purines/pyrimidines	1.46	
Nitrogen	150.0	10.7			
Nitrogen calculated from bases	149.0	10.6			

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CURRENT FISHERIES RESEARCH BY CANADIANS ON THE GREAT LAKES

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Abstract

The activities indicated are reviewed. They fall into two categories: 1. A contribution towards eliminating sea lamprey from the Great Lakes; 2. Some general fishery research.

The activities considered are those that until now have been sponsored by the Federal-Provincial Great Lakes Fisheries Research Committee, a group of eight, four representing the government of Canada and four the government of Ontario. It was formed in 1953 both to initiate immediate action to control sea lamprey and to intensify general research on the Canadian fisheries of the Great Lakes. Since these activities are included in the duties assigned to the recently formed Great Lakes Fishery Commission the Committee's program is now being absorbed into the more general program of the Commission.

The Committee was formed with the understanding that the Canadian government would finance most sea lamprey control activities while the Ontario government financed all biological reasearch that was not concerned with lampreys. Lamprey control measures were to be considered as experimental and initially to be concentrated on Lake Superior. The Committee named a sub-committee of two members, F. E. J. Fry and W. M. Sprules (who were designated as co-directors) to implement its program. The co-directors asked J. M. Speirs to act as secretary of their two-man sub-committee with responsibility for day-to-day supervision of the program. Later, I was asked to direct the Committee's program temporarily in addition to my normal duties, and took charge on April 1, 1955, with the title "Co-ordinator of Research."

Although control of the sea lamprey was not the most important problem, it was regarded as the most pressing one. The sea lamprey had already made it unprofitable to fish for lake trout in Lake Huron and in Lake Michigan and seemed likely soon to do the same in Lake Superior. The need to bring the lamprey under control as soon as possible seemed urgent enough that it was decided to begin immediately the use of a control technique developed by the U. S. Fish and Wildlife Service even though it would not necessarily be as effective under the different

Reprinted from Volume 86 (1956), Transactions of the American Fisheries Society.
Published 1957. Printed in U.S.A.

FRB No. 495

conditions found in Ontario. The technique, which is described in published papers, consists of stopping lamprey from ascending their spawning streams. In most situations the movement of lampreys is blocked by placing electrodes in the water from bank to bank to produce an electrical field in the stream that immobilizes or kills lamprey. In a few streams it is practical to use mechanical barriers rather than electrical barriers.

In 1953 three barriers were built in Canada in the immediate neighborhood of Sault Ste. Marie and more were built in 1954, 1955, and 1956. By the end of 1956 every stream on the Canadian side of Lake Superior in which lamprey are likely to spawn will have a barrier—a total of approximately 40 structures.

Barriers are installed in those streams where sea lamprey are known to spawn or in streams where it seems likely that they will spawn as their numbers increase. In addition to streams with barriers, more than 100 Canadian tributaries to Lake Superior are kept under observation to see whether lamprey runs will develop in them. Whenever possible, several visits are made to these streams during each spawning season to see whether lamprey are spawning in them. On many of them,however, the spawning grounds are so difficult to reach that it is not practical to make these observations. "Check weirs" are installed near the mouths of such streams. These weirs are actually traps designed to catch and hold all lamprey that attempt to ascend the stream.

It soon became apparent that the type of electrical barrier developed in the United States was not altogether suitable for conditions on the north shore of Lake Superior. In many Canadian streams barriers of this type failed to produce an electrical field that always killed sea lamprey. It has since been found that barriers suitable for Michigan streams failed in Canadian streams because of a difference in electrical resistivity. In the streams on the south side of Lake Superior resistivity averages about 8,000 ohms per centimeter cube as compared with an average of 20,000 ohms in those on the north shore (range 4,200 to 40,600, most readings between 15,000 and 25,000). This difference is not surprising since resistivity is inversely related to the amount of material dissolved in the water and since the north shore streams generally drain extensive areas of relatively insolvable precambrian granite. Therefore electrode arrays which would produce a satisfactory electrical field in waters of relatively low resistivity proved inadequate in Canadian streams where resistivity was considerably higher.

To overcome this difficulty, two new arangements of electrodes were developed which would increase the current used by a given barrier and thereby increase its blocking effect to a satisfactory level. The arrangement most commonly used is called the modified ground electrode and is simply an elaboration of the ground electrode used in the United States. It differs by having four lengths of pipe parallel to one another instead of the single lengths of pipe found in the ordinary ground elec-

trode. This modified ground electrode is effective in water as much as 3 or 4 feet deep. For greater depths the "rack-type" electrode arrangement is used. This barrier has horizontal electrodes much closer together than was practical with the hanging electrodes used originally. The prototype of another type of electrical arrangement is being tested in which wooden pilings are driven into the bottom solidly enough to resist floods and ice, and each pile is sheeted with metal to make it into an electrode.

Another difficulty was probably also the result of differences between conditions on the two sides of the lake. Within the electrode array of the original barrier there was a trap designed to catch alive all migrating fish so that they could be released beyond it. None of these traps was effective under Canadian conditions; eventually the use of this type of trap was abandoned. Instead a modified pound net is now set below each barrier to intercept migrating fish before they reach the lethal electrical field. This arrangement proved to be so effective that the fish kill in 1956 was negligible compared with the kill in 1955.

The known kill of sea lamprey at Canadian barriers on Lake Superior was 2,131 in 1955 and will be about 2,400 in 1956. Probably many of the lamprey killed are carried away by the current, or are not seen because of muddy water. The number recovered is therefore presumed to be less than the number actually killed although there is no way of judging how much less. Flood conditions in 1956 made recovery of dead lamprey more difficult than in 1955, which suggests that the actual kill might have increased by considerably more than is indicated by the small increase in number recovered. Practically all of the lamprey recovered in 1956 were killed by barriers within 100 miles of Sault Ste. Marie even though devices were operated much further away. This may indicate that sea lamprey are well established only in the southeast corner of Lake Superior.

The first barriers to be put into operation were those on the few Canadian tributaries which have sizeable sea lamprey runs. Barriers have been operated on all such streams since the beginning of the 1955 season. Although the barriers have not been completely effective, observations on the spawning grounds above them have indicated little escapement. Therefore, it seems likely that very few sea lamprey have spawned in Canadian tributaries of Lake Superior since the spring of 1954. In other words the expected contribution of Canadian streams to those year classes of lamprey which normally would have been available to prey on the fish of Lake Superior in 1959 and 1960 has probably been greatly reduced.

The many difficulties encountered in trying to prevent sea lamprey from spawning have emphasized so strongly the need for more information about them that considerable effort has been put into research on the animal. A study is being made of the exact conditions needed for successful lamprey spawning; it has shown that they can spawn successfully in water where there is absolutely no current. A study of sea lamprey ammocoetes has shown that they move considerably and even migrate from one

tributary to another so that they may be found in streams where spawning is impossible. A team of divers has been studying sea lamprey by direct underwater observations; so far they have produced considerable evidence that few adults pass through the canal at Sault Ste. Marie during the summer . Lamprey physiology is being studied with particular emphasis on the effects of electrical fields on the animal. Financial support is being given to Kleerekoper of McMaster University for physiological work; he has discovered that sea lamprey produce spike potentials which recur at 0.4-second intervals and that the resulting electrical field is around the head and forward from it.

In addition to the foregoing which are financed by the Federal government, some lamprey control has been financed by the Provincial government. The most important have been a number of stream surveys to get the information necessary for determining where barriers are required. Another contribution has been the collection of information on the extent to which various species of fish are scarred by lamprey. This information is collected through questionnaires to the commercial fishermen and is periodically tabulated and made available to all concerned.

The main contribution of Ontario to the Committee's program has been in the form of financial support of fishery research. The biggest operation is at South Bay on Manitoulin Island, Lake Huron, where work recently done under the Committee has been simply a continuation of research started there almost a decade ago and which is well known through published papers. South Bay can be regarded as a microcosm where techniques for working on larger bodies of water can be developed. A good deal of information has been collected on the fish of South Bay and there seems to be a good chance that when it is analysed a formula will emerge which will show fish production in South Bay can be maximized. Since maximization of production is a major problem on all the Great Lakes this development within the South Bay microcosm promises to be of great general interest.

Considerable numbers of the lake trout × speckled trout hybrid known as "splake" have been planted in South Bay. The hybrid grows faster than either of the parents and appears to be much less susceptible to lamprey attack. None of the considerable numbers of marked lake trout recently planted in South Bay have managed to survive lamprey attacks long enough to reach maturity, but this is not true of the splake.

A start has been made on extending the studies at South Bay to Lake Huron as a whole. Personnel based at the South Bay Laboratory have also been studying Lake Superior fisheries. Of almost 6,000 Lake Superior trout tagged in 1954 and in 1955 enough were recovered by commercial fishermen to indicate an intensive fishery. The tagged trout travelled considerable distances and a few crossed the international boundary. Some records of Lake Superior commercial fishermen were also studied; they show that for several years catch per net has been declining.

In Lake Erie much information has been accumulated by examining the commercial catch; to date these data are not analysed. The Lake Erie group has also been cooperating with biologists in the United States, particularly those in Ohio, to tag Lake Erie fish as a means of studying their movements. This study is by no means complete but the data indicate that practically every species of commercial fish in Lake Erie moves extensively and that migration across the international boundary is common.

On Lake Ontario an experiment to determine the effectiveness of planting whitefish fry as a management technique has been going on for some time and is now almost completed. The experiment consists of using standard techniques for hatching and planting whitefish fry except that the fry are planted only in alternate years. The composition of fishermen's catches is studied in subsequent years to see whether the year classes which were reinforced by hatchery plantings are stronger than the year classes which were not so reinforced. The data so far collected tend to show that plantings do not influence year-class strength appreciably.

The group on Lake Ontario is also cooperating with New York State investigators in an experiment to determine whether the planting of lake trout fingerlings is likely to be an effective way to rehabiltate the trout populations of the lake. The experiment is incomplete but examination of small lake trout (below legal size) indicates that the planted fish (which were marked) are contributing significantly to the oncoming year classes.

Provincial investigators have been collecting limnological data on the Great Lakes and have had an informal working arrangement with United States scientists for taking simultaneous limnological observations. Particular emphasis has been put on Lake Huron but considerable work has been done on Lake Erie and some on Lake Ontario. A report on the 1954 Lake Huron surveys will be published shortly.

Estratto dalle « Pubbl. Staz. Zool. Napoli » - Vol. XXX *(Pubbl. il 15-VIII-1957)*

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Removing Intact Bivalves from Their Shells*).

(ricevuto il 3-X-1955).

Bivalve molluscs for dissection or microtomy are most useful if they are killed after narcosis so that their mantles and gills are fully extended and their siphons and feet not violently contracted, and removed from their shells without cutting the muscles. The writer finds the following technique effective :

1. Narcotize marine species by overnight immersion in

Tapwater	10 parts
Seawater	10 parts
Magnesium Sulphate, $MgSO_4 . 7H_2O$	1 part

2. Quickly and gently drain the liquid from the shell.

3. For microtomy, place the animals in a large volume of Bouin's fixative, excluding bubbles from the shell; for dissection, place the animals in

Tapwater	20 parts
40 % Formaldehyde solution	2 parts
Glacial acetic acid	1 part

After 24 hours in either solution, the upper valves of small oysters will usually be detached from the adductor muscle, and the oyster may be gently lifted from the lower valve (which it fits snugly) with a scalpel handle, preferably floating it out in a dish of water. Oysters over 5 cm. long usually require another day or two of treatment, replacing the solution whenever effervescence from the shell ceases. In mussels, the border of the mantle must be freed from the shell with a probe or forceps after 24 hours treatment; another day will permit the animal to be lifted from the shell. Unfortunately, in *Mactra*, *Mya*, and *Venus*, the muscle insertions do not seem to be effectively eroded by acid diffusing through the tissues, and the process degenerates into dissolving the entire shell.

Other acid fixatives may be effective; Zenker's, however, is useless; it detaches muscles from the shell but fixation is atrocious. Acetic acid is better than strong mineral acids which waste themselves on the outside of the shell before they can penetrate the muscles and work from within.

Molluscs prepared in this way are superior to the usual contracted, distorted specimens cut from their shells. They clearly display the complex mantle folds and extensions near the hinge in *Mactra* and the correspondence in shape between mantle and shell in abnormally shaped *Crassostrea;* the integrity of the ends of the muscles facilitates injection; and sections of entire small specimens diagrammatically illustrate the anatomy of the animals.

*) This work was carried out at the Prince Edward Island field station for oyster research, Ellerslie, Prince Edward Island. **FRB No. 496**

eprinted from pages 23-25 of the Annual Proceedings, International
mmission for the Northwest Atlantic Fisheries, Vol. 4, for the
ar 1953-54:
rt 3: Summaries of Research 1953 - Summaries by Countries.
lifax, N.S., Canada, 1954.)

Summary of Canadian Groundfish Research in the Convention Area During 1953

SUBAREA 2. By W. TEMPLEMAN[1]

Between September 7 and 18, 1953, Hamilton t Bank was explored by the Investigator II g a No. 36 otter-trawl. Forty sets were le well distributed over the bank and its es.

Cod *Gadus callarias*, L. On the western e of the bank cod catches were usually low the bottom was rough. Cod fishing on the k itself, at depths between 150 and 183 m., good in many areas. On the eastern slope re were excellent catches in several areas from to 208 m. with moderate catches down to m. There were a few minus temperatures none below -0.5°C. and in the areas where were plentiful no temperatures over 2.7°C. the largest two catches per hour's dragging 3700 kg. catch was at 0.1°C. and the 3000 kg. ch at 2.7°C. The six catches of 1500 to 1700 per hour were at temperatures between -0.5 0.9°C., and 6 of 1000 to 1100 kg. at tempera- s between -0.3 and 1.9°C. In the deeper er, 310 to 350 m. to the east of the bank and h higher temperatures of 3.1 to 3.4°C. cod scarce and redfish more abundant.

The Hamilton Inlet cod are of medium but stly commercial size. In the autumn they are good condition with very fat livers.

American Plaice *Hippoglossoides platessoides* (Fabricius). While there were some American plaice everywhere on the bank, in only one ity were they plentiful enough to supply a mercial fishery for plaice alone. This was 179 to 183 m. in latitude 54°22'00"N. and itude 54°48'00"W. where plaice were obtained e rate of 2800 kg. per hour's dragging. The om temperature was 0.4°C. In 1952 the large catch of plaice was only 12 kilometres n this point in 183 m. and -0.3°C. where ice were caught at the rate of 3700 kg. per r's dragging. The good American plaice nds on this bank therefore are probably ted in area.

Hydrography. During July 31 and ust 1 a hydrographic section was taken across Labrador Current off Domino Point and south Hamilton Inlet Bank.

SUBAREA 3. By W. TEMPLEMAN

Cod and Haddock *Melanogrammus aeglefinus* (L.). Recaptures are still being made from the 4715 cod tagged at St. John's and Fogo in 1950. Eliminating the unsuccessful bachelor-button tag the average percentage returns per year have been 1950—6.7, 1951—12.8, 1952—4.5, 1953—1.6. During the first year tagging was deliberately delayed until most of the fishing was over. The most effective tags have been a two-inch red tag of cellulose nitrate attached to the pre-opercular by nickel wire—38.7% return, a 13/16-inch pink cellulose nitrate tag attached below the anterior base of the first dorsal—33.0% return, and a five-inch orange vinylite plastic body cavity tag with a 32.1% return. In returns subsequent to the tagging year the best tags gave 25-32% recapture and the poorest (the bachelor-button type) only 4.6%.

In May an otter-trawl survey of cod and haddock populations on the southern half of the Grand Bank was carried out by the Investigator II. In a good part of the area examined, namely the northern half of the southwest slope of the bank, there was at depths of 71 to 82 m. a well marked contrast in bottom temperatures between adjacent sets only a few kilometres apart from north to south. The large concentrations of haddock were on the southern high temperature side of the temperature break, in temperatures between 2 and 7½°C. and depths between 75 and 93 m. Where the high temperatures of 4 to 8°C. were present in deeper water of 110 to 180 m. haddock were scarce, showing that by May the haddock were moving toward shallower water and that both depth and temperature were factors. The cod were not in abundance, but were considerably more plentiful on the lower temperature northern side of the break in temperature, at temperatures from 2.0 to less than one degree centigrade and depths from 80 to 59 m.

On both the Grand Bank and St. Pierre Bank the most plentiful group of haddock was the 1949 year-class with a peak length of 36-37 cm. and this year-class, except for the largest specimens, was discarded by Newfoundland trawlers. The haddock landed at St. John's and Burin from the Grand Bank had a peak size of 50-51 cm. and con-

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sisted mainly of the 1946 year-class with a significant number of the 1942 year-class and with very few of the intervening year-classes. The 1949 year-class is a very great one which should provide good fishing for several years on both the Grand Bank and St. Pierre Bank.

In two Grand Bank commercial trips investigated, 67% of the haddock by number were discarded as compared with 18% in 1952. The high proportion thrown away in 1953 was due to the large numbers of four-year-old 34 to 40 cm. haddock which were caught this year for the first time, but were too small to land. On St. Pierre Bank during one commercial trip the number of haddock discarded was 74%. The weight of haddock discarded in the three trips as estimated from length frequency data was 42%. In 1952 it was estimated that only 9% of the haddock by weight were discarded.

Redfish *Sebastes marinus* (L.). In the past few years commercial development has been proceeding over much of the redfish area explored by the Investigator II between 1946 and 1950. During July, 1953, commercial development began of the plentiful stocks of large redfish found by the Investigator II in 1950 in 290 to 365 m. off the northeast corner of the Grand Bank. Since late summer to early autumn, 1951, trawlers (mostly United States, but with some Nova Scotian and a few Newfoundland) have been engaging in successful commercial fishing for large redfish in the deep water channels of the Gulf of St. Lawrence where general redfish abundance was indicated by the explorations of the Investigator II from 1947 to 1950. The larger vessels of the United States fleet have been carrying out a good deal of fishing during the past three years on the southwest slope of the Grand Bank which had been successfully explored for redfish down to 365 m. by the Investigator II between 1946 and 1951. The east coast Newfoundland redfish vessels concentrate on the larger redfish of the eastern edge of the Grand Bank. It is evident that overexploitation of redfish in one favourable area can occur. The formerly abundant redfish population within a few kilometres of Ramea from which many millions of pounds of redfish have been taken since 1946 has apparently been reduced below the level of profitable fishing.

In 1953 the Investigator II carried out in two areas an exploration for redfish in 275 to 595 m. Unsuccessful attempts were made to drag to 730 m. An otter-trawl was used with both otter-boards attached to a single wire. In a July trip to the southwest slope of the Grand Bank redfish were most numerous between 275 and 365 m. and with no commercial amounts below 365 m. although there were some redfish in drags at least as deep as 455 to 550 m. There was a general increase of size in both sexes with depth. In October a similar exploration was carried out in an area northeast of Bonavista. Due to bad weather only 9 drags could be made between 300 and 730 m. The net was apparently not on bottom below 595 m. The best catch of 1850 kg. of redfish per hour's dragging was made at 350 m. and catches of 40 to 110 kg. per hour's dragging were made at 520, 550 and 605 m. In the successful drags in these three latter depths numbers of large grenadiers (*Macrourus*), which are bottom fish, were obtained showing that the net was fishing near the bottom. It is unlikely that the redfish in the 520 to 605 m. sets were caught as the net was passing upward through shallower layers, since in the two drags when the net was fishing at 695 to 730 m. and was not on bottom but was deeper than 605 m. no redfish were caught. There was little or no significant difference in size of the redfish at the various depths.

Redfish otolith age readings are well under way and some differences in growth-rate in various areas are evident.

Examination of redfish stomachs has shown the percentage stomach eversion increasing with depth from 32% at 295 to 345 m. to 65% at 600 m. In 142 stomachs containing food the total volume of food present was made up of 67% amphipods, 18% fish, 13% copepods, 2% squid and 1% euphausians. Numerically 84% of the stomachs contained amphipods, 74% copepods, 16% euphausians, 12% fish and 7% squid. The food generally consisted of free-swimming and not bottom organisms.

American Plaice. Estimations of the age of American plaice from their otoliths show considerably higher rate of growth for the Grand Bank than for the inshore Notre Dame Bay area. The rate of growth in general appears to be slow and some plaice were over 35 years of age. The numbers of eggs in the ovaries of American plaice ranged from 156,000 at 45 cm. and 12 years to 1,412,000 at 74 cm. and 37 years of age.

Population Identification and Study Studies of vertebral and fin-ray number were continued on all the main groundfish species. Offshore landings were measured, and scale and otolith samples collected continually at St. John's and Burin. Amounts and location of catches and also effort statistics were obtained from almost all trawlers, also for long-line vessels and Danish seiners. Age estimations were carried out on cod, haddock, redfish, American plaice and witch *Glyptocephalus cynoglossus* (L.).

In the various exploratory fishing operations and in the statistical study of commercial fish landings 72,000 cod, 20,000 redfish, 31,000 haddock and 14,000 American plaice have been measured during 1953.

M.V. "Marinus". In early November a 19 m. research boat, the Marinus, built at aquet, N. B., became available to the Station. s boat is equipped to otter-trawl to three dred and fifty m. and will also be fitted with dining gear.

Hydrography. Three hydrographic sections across the southern part of the Grand Bank were occupied in April. These were repeated in July-August together with two additional lines of stations across the Labrador Current, off Bonavista and from St. John's along the 47° latitude line to beyond Flemish Cap.

(Reprinted from pages 25-27 of the Annual Proceedings, International Commission for the Northwest Atlantic Fisheries, Vol. 4, for the year 1953-54:
Part 3: Summaries of Research 1953 - Summaries by Countries.
Halifax, N.S., Canada, 1954.)

I. Summary of Canadian Groundfish Research in the Convention Area During 1953

SUBAREA 4. By W. R. MARTIN[1]

At the third Annual Meeting of the Commission a group of "Scientific Advisers to Panel 4" was established to review the status of the groundfish stocks and to determine research and conservation requirements in Subarea 4. Canadian groundfish research in the subarea was reviewed at meetings of this group held at Copenhagen in October and at St. Andrews in December, 1953.

Identification of Stocks—A manuscript has been prepared for publication describing the results of vertebral counts on some 38,000 **cod** in 375 samples made in 1933 to 1941. The conclusions are in agreement with the results of tagging carried out during the same period, but more detailed information has been provided on the different cod populations in Subarea 4.

Returns from more than 7,000 **haddock** tagged between 1935 and 1940 have been described in manuscript form for publication. Deep channels, water temperature, spawning and feeding proved to be important factors controlling the movements of haddock populations. A number of discrete populations have been recognized within Subarea 4.

The M.V. "J.J. Cowie" was used during the months of May to October, 1953, to study the distribution and movements of **redfish** along the upper Laurentian channel in the Gulf of St. Lawrence. Redfish were most plentiful off the western tip of the Gaspé at depths of 175 to 300 m.; the size modes for males and females were 35 to 36 and 38 to 40 cm. respectively. Larger fish of both sexes were found in deep water. Mature females were 50% spent in June with the largest fish spawning first. Both sexes were feeding [illegible] June and early July but from August to October the females were eating less and all males were empty. Fifty percent of the redfish were mature at 25 cm. The appearance of small redfish (down to 20 cm.) in much greater numbers in the St. Pauls-Bird Rocks area of the southern Gulf suggests that redfish larvae liberated in the Gulf are carried south toward Cabot Strait with the dominant outward movement of Gulf water.

Seasonal changes in catches appeared to be related to changes in vertical distribution rather than extensive movements of redfish. There was a consistent decrease in catches after dark with males showing a more pronounced movement off bottom. At spawning time females tended to be off bottom as demonstrated by greater catches of males in bottom dragging.

A manuscript describing "The Seasonal Distribution of the **Winter Flounder** *Pseudopleuronectes americanus* (Walbaum) on the Atlantic Coast" describes changes in depth distribution in relation to environmental factors, particularly temperature and light.

Statistics—Four field technicians collected (1) detailed statistics on area fished and fishing effort for a large proportion of offshore landings; (2) samples for length and age composition of both inshore and offshore landings; (3) measurements of quantities of haddock discarded at sea. These observations, together with statistics of landings collected by the Department of Fisheries, provide essential information on yield, indices of abundance, recruitment, growth and mortalities.

Total groundfish landings decreased during 1953, the most pronounced change being a 27% (28,000 metric tons) reduction in landings of cod from Subarea 4. The decreased cod landings were compensated in part by increased landings of redfish from Subarea 4, and of haddock and flounders from Subarea 3. The drop in cod landings is partially related to the decreased abundance of large steak cod, but a change in economic conditions, involving a 25% decrease in price and buyers' quotas on landings, was the dominant factor in the reduced landings.

In the haddock fishery the 1948 year-class was dominant in landings by Western Nova Scotia boats. In the landings from offshore banks and the Cape Breton area the 1947 year-class was dominant. The 1949 year-class has become important to the haddock fishery in the southern Gulf of St. Lawrence and on Banquereau. In the cod fishery the 1948 and 1950 year-classes were important in the western Nova Scotia area. The

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1953 Groundfish Tagging off Southwestern Nova Scotia with Recoveries to December 31, 1953

Type of Tag	Cod			Haddock		
	No. Tagged	No. Recovered	% Recovery	No. Tagged	No. Recovered	% Recovery
Hydrostatic	933	229	24	276	13	5
Red and white disks	305	114	37	98	6	6
Yellow disks	303	92	30	87	8	9
Strap	263	32	12	119	5	4
Total	1804	467	26	580	32	6

1947 year-class was dominant in landings from offshore banks and the Gulf of St. Lawrence.

Tagging—1,804 cod and 580 haddock were tagged off Lockeport, Nova Scotia, between May 27 and October 20, 1953. The fish were taken by hook and line fishing from the M. B. "Mallotus", with holding tanks and tagging troughs used to facilitate release of fish in good condition. All tags other than strap tags were attached by stainless steel wire between the first and second dorsal fins. The strap tags were clamped on the lower fleshy portion of the tail.

Early returns of tagged cod suggest a relatively high fishing mortality. Recoveries of tagged haddock were low in 1953, but the number of recoveries increased early in 1954. In both species most recaptures have come from the tagging region.

Population Dynamics—Analysis of records of the fishery and of tagging experiments on a distinct population of the winter flounder in St. Mary Bay, Nova Scotia, provided good estimates of growth, natural and fishing mortality and recruitment for the construction of yield- and value- isopleths based on the method described by R. J. H. Beverton. Results provide a basis for judging the desirability of any regulation of this fishery and indicate that under present conditions any restriction of fishing will tend to reduce landings and value. This study has served to demonstrate the usefulness of this method of analysis, and cod and haddock stocks will be studied along similar lines.

Mesh Selections—Experiments with large-mesh cod ends on three commercial otter-trawler trips demonstrated that small haddock and cod are effectively released and as a result the industry is voluntarily adopting large-mesh cod ends of about 4 ½" inside measure after use. Five mesh sizes from 4 ½" to 5 ½" inside measure were compared with the standard 2 ¼" mesh by covered net and comparative tow experiments. Mesh sizes larger than that now in use on Georges Bank gave 50% selection points for both cod and haddock which were in line with results of earlier mesh experiments (fig. 8, p. 31, 2nd Annual Report ICNAF). Large catches dampened the selection effect of the meshes.

Hydrography— Canadian hydrographic investigations by the Atlantic Oceanographic Group continue to lay the basis for a better understanding of the natural factors causing changes in the abundance and movements of groundfish and other species.

Seasonal cruises over the Scotian Shelf, Bay of Fundy and Gulf of St. Lawrence were carried out in September and November. Temperature and salinity data from seasonal cruises between 1946 and 1952 have been prepared in the form of plots of temperature and salinity distributions in sections.

A report has been prepared on the bottom temperatures on the Scotian Shelf from the data obtained during seasonal cruises. The three layer stratification of the waters, the influence of the slope water, and of cold waters to the northeast, make bottom temperature a complicated function of depth, location and time. In general the lowest bottom temperatures are found in the northeast sector and the highest on the shoal banks and in the deep areas of the Scotian Gulf. Maximum bottom temperatures have been observed to be as much as two degrees higher than those recorded over the area in pre-war years.

Continued observations of surface water temperatures, taken twice daily at strategic points along the Canadian Atlantic coast, have shown a general warming of the waters during the last 13 years. The period 1949-52 is recognized as being the warmest quinquenniad on record with peak temperatures occurring in general in 1951. The peak temperatures were equalled or closely approximated in 1953, particularly in the early months of the year. The late fall observations show a considerable abatement.

A better appreciation has been obtained of the rapidity with which major changes can occur. In November, 1952, for example, a large-scale replacement of Bay of Fundy water took place in three weeks. An important study has been made of the "slope waters" lying between the coastal waters of the Scotian Shelf area and the Gulf Stream. Incursions of this water are responsible for sudden changes in conditions on the banks, with greatest influence around Emerald, LaHave and Western Banks.

eprinted from pages 19-22 of the Annual Proceedings, International
mission for the Northwest Atlantic Fisheries, Vol. 5, for the
ar 1954-55:
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I. Canadian Researches, 1954

SUBAREA 2. BY W. TEMPLEMAN[1]

Redfish *Sebastes marinus* (L.). In Septer, 1954, the "Investigator II" carried out oratory fishing for redfish in the deep water of Hamilton Inlet Bank in Labrador. A ll net, the three-quarter 35 otter trawl (39 eadrope), was used on a single wire. A series ve drags, fairly well distributed over the day- hours, was carried out at each of five depths een 160 and 400 fathoms. The average h of redfish per hour's dragging at the dift depths is shown in Table 1. There is at ent no commercial fishery for redfish in this

Redfish sizes increased with depth. Some large redfish of 60 to 70 cm. were present; of 75 cm. and 19 pounds was captured. There a very great difference in the size at sexual rity of the fish in different depths. Whereas sample from 160 fathoms, the largest imure females were 37 cm. and the smallest re spent females were 35 cm., only 5½ nautis miles distant in 300 fathoms there were no ure specimens in a sample of 21 female red- of 32-39 cm. or in a sample of 39 of 40-47 cm.

With the higher temperatures, which usually favour early maturity, occurring at the greatest depth (see the table) the lack of mature specimens at 300 fathoms was apparently due not to temperature but to some other factor such as lack of light.

The area surveyed is the chief centre of infection of redfish in Canadian Atlantic waters by the copepod parasite *Sphyrion lumpi*. The data on parasitization, collected from large numbers of redfish examined at sea, are shown in Table 2.

Great differences in the distribution of the parasite *Sphyrion* occurred in samples only a few miles apart, four miles in the case of the highly distinct redfish populations from 200 and 250 fathoms. Samples of redfish from 160 and 300 fathom depth, from localities on Hamilton Inlet Bank only 5½ nautical miles apart, were examined at the Research Station. 8.8% were infected externally with *Sphyrion* at 160 fathoms and 0.8% at 300 fathoms. After removal of the heads of the living *Sphyrion* the fillets of these samples, each of 120 fish, were examined on a candling table for old heads of *Sphyrion*. Internally, 19% of the fish at 160 fathoms and

ble 1. Observations on Redfish from Sets East of Hamilton Inlet Bank

Depth Fathoms	160	200	250	300	390-400
tom Temp. °C.	2.1	3.1	3.9	3.9	—
Catch per hour dragged (lbs.)	1,820	2,280	1,330	770	10
Size (cm.)	32.5	33.7	35.3	39.0	—
est Immature Female (cm.)	37	—	—	47 *	—
allest Mature Female (cm.)	35	—	—	None*	—

mature specimens were found in a sample of 21 females of 32-39 cm. nor among 39 females of 40-47 cm.

ble 2 Parasitization by *Sphyrion lumpi*

Depth Fathoms	160	200	250	300
Observed at Sea				
% Parasitized by Living *Sphyrion*	5.8	6.2	1.3	0.8
No. of *Sphyrion* per 100 fish	8.7	9.2	1.4	0.8
From Laboratory Samples				
% Parasitized by Living *Sphyrion*	8.8	—	—	0.8
% of fish with old heads in fillets	19	—	—	8
No. of heads per 100 fish	42	—	—	9

rector, Fisheries Research Board of Canada, Biological Station,
t. John's, Nfld.

Fig. 1a. Hydrographic section, Hamilton Inlet Bank, 30-31 July 1954. Temperature °C. Position of section inserted. The close-lying isotherms of the surface water are only indicated.

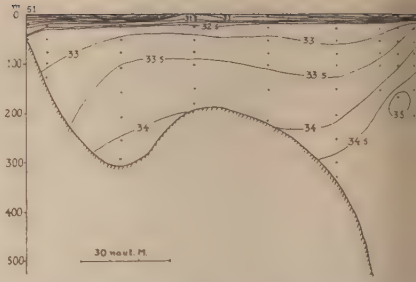

Fig. 1b. Hydrographic section, Hamilton Inl Bank, 30-31 July 1954. Salinity °/₀₀.

8% at 300 fathoms had encysted heads. There were 42 encysted heads per 100 fish at 160 fathoms and only 9 at 300 fathoms and this in spite of the considerably greater size of the redfish at 300 fathoms.

The living *Sphyrion* most likely have a life history of at least a year and the differences in distribution in the samples only 4 to 6 nautical miles distant, but with 50 to 140 fathoms difference in depth, indicate extremely little interchange in the redfish at different depths in the same area and also that the free-swimming stages of *Sphyrion* and the secondary host, if one exists, are largely restricted to depths above the 250 fathom line.

There was an absence of mature fish at 47 cm. length at 300 fathoms, while at 160 fathoms, 5½ nautical miles distant, the smallest mature female was 35 cm. and all females over 37 cm. were mature spent fish. This indicates a lack of mixing for many years.

It appears very likely, therefore, that once the redfish become adjusted, possibly at an early age, to depths of 160 to 200 or 250 to 300 fathoms it is very difficult for them to pass from one of these depth ranges to the other.

Hydrography. The section across the Labrador Current (Hamilton Inlet Bank, Fig. 1) was taken on July 30-31. The water in this section was much colder in 1954 than in 1953.

SUBAREA 3. BY W. TEMPLEMAN

Haddock *Melanogrammus aeglefinus* (L.). In May and early June the yearly haddock otter-trawl survey was carried out by the "Investigator II."

The 1949 year-class which formed most of the commercial catch was abundant on Grand Bank and St. Pierre Bank; there was little evidence of the 1950 and 1951 year-classes. The 1952 and 1953 year-classes were abundant on the Grand Bank while on St. Pierre Bank the 1952 year-class was very scarce and the 1953 yea class abundant only in one small area.

Redfish. In Hermitage Bay, through t trawling of the "Marinus", a small-redfish fr quency peak was found with peak sizes at a proximately 7¼ cm., December, 1953; 8¼ cm June, 1954, and 8¾ cm. in September, 195 These fish were most likely about 1½ years o in December, 1953. There are three well defin groups of fish and this will allow observations a checks on the age and growth of redfish. The are, judging from growth studies in other area about eight years between the younger grou of fish and the older successful group of redfi in Hermitage Bay with a peak of 22 to 23 c There was apparently very little settling of you redfish in the area in the intervening yea Since the large-meshed trawl net with a shrim net cover probably does not catch the smalle group efficiently, it is difficult to know at prese whether this group of tiny fish will represent considerable stock.

Fishing for redfish usually ceases at nig since redfish in many areas rise from the botto and are no longer available in quantity to t trawls. During the last half of June and the fir half of July, two trips were made to investiga the availability of redfish at night. In the sout west Grand Bank area there were indicatio that at 160 fathoms, catches were normal fro 6 a.m. to 6 p.m. and dropped off to as low as to 15% of the daytime catch by 1 a.m. In t northeastern Grand Bank region at 160 fathom a catch of 1,500 pounds in a half-hour's drag w obtained at 11.10 to 11.40 p.m. and one of 8 pounds from 2.35 to 3.05 a.m. These compare with catches ranging from 800 to 6,500 poun or an average of 2,200 pounds during the da light hours.

Tagging. Thirteen thousand cod *Gadus c larias* L. were tagged in 1954. The tagging are were Burgeo Bank, St. Pierre Bank, St. Anthon La Scie, Bonavista, Fermeuse, Cape St. Mary and Trepassey. Many varieties of tags were us in an attempt to find the most suitable tags f future work.

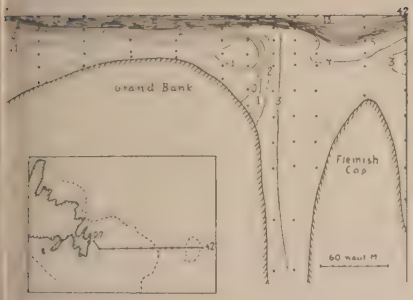

Fig. 2a. Hydrographic section, Grand Bank-Flemish Cap, 24-26 July 1954. Temperature °C. The inset shows position of section. The close-lying isotherms of the surface water are only indicated.

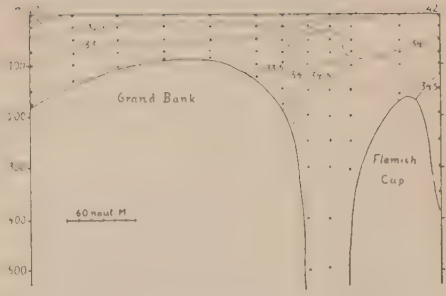

Fig. 2b. Hydrographic section, Grand Bank-Flemish Cap, 24-26 July 1954. Salinity °/₀₀.

Five hundred American plaice, *Hippoglossoides platessoides* (Fabr.) were tagged in St. Mary's Bay and 1,000 on the northern slope of the Grand Bank.

Mesh selection. Covered net experiments on haddock were carried out on several trips in the "Investigator II". The 50% selection point for haddock was 36 cm. for a 4 1/8 inch mesh and 31 cm. for a 3 3/4 inch mesh cod-end. An attempt using similar trawlers to show that the large 4 1/2 inch mesh cod-end was more efficient than the new 3 inch mesh cod-end in common use, was unsuccessful since most fish were in the 35-46 cm. range with a modal size of 39 cm. The fish boats were accepting small round haddock down to 35 cm. and the large-mesh gear caught such small catches of these small haddock that it was unprofitable to use it.

Statistics and population sampling. Catch, location and effort data were obtained for inshore boats and the offshore catch was measured and sampled at St. John's and Burin and the inshore catch at St. John's, Burin and Bonavista. A new departure during the year was a change in the haddock fishery toward the landing of haddock in the round condition and toward landing smaller haddock. By the end of the year over 90% of the haddock were being landed round. The haddock catch during the year increased greatly, and the cod were very abundant in the inshore areas and very close to the shore.

Hydrography. A hydrographic survey on the southern half of the Grand Bank and on St. Pierre Bank was carried out in April.

In July and August five hydrographic sections were taken across the Labrador Current and the banks from Bonavista to the southern edge of the Grand Bank. The section Grand Bank to Flemish Cap is shown in Fig. 2.

Inshore, the surface layer of warm water was extremely shallow. The 0°C. line remained at twenty fathoms until the end of August and the 3°C. line above twenty fathoms till early September.

In the Labrador Current from Labrador to Cape Bonavista and in the inshore branch of the current from Cape Bonavista to the southern edge of the Grand Bank there was a considerably greater volume of below 0°C. water present in July-August, 1954, than in the same period of 1953.

eprinted from pages 22-27 of the Annual Proceedings, International
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Canadian Researches, 1954

SUBAREA 4. BY W. R. MARTIN[1]

The researches in Subarea 4 were carried out by the Marine Biological Station of the Québec Department of Fisheries and by both the Newfoundland Fisheries Research Station and the Atlantic Biological Station of the Fisheries Research Board of Canada. Studies of redfish, cod tagging, mesh selection, hook selection, fish larvae and hydrography were pertinent to ICNAF interests. Abundance, growth and mortalities of the most important groundfish species were followed by sampling commercial landings. Emphasis was placed on an assessment of the need for mesh regulation in Subarea 4 and to this end, the following submissions were made to the Commission:

Canadian investigations of Subarea 4 stocks of cod and haddock.

A. Factors affecting annual yield—by W. R. Martin (ICNAF Ser. No. 268)

B. Gear selection in relation to sizes caught and landed—by F. D. McCracken (ICNAF Ser. No. 269).

C. The effect of increased mesh size on yield—by J. E. Paloheimo (ICNAF Ser. No. 274).

Redfish. Seasonal and diurnal movements of redfish in the Gaspé area of the Gulf of St. Lawrence were studied from the "J. J. Cowie" during the period May to September.

Seasonal changes in the sex ratio of redfish taken in a 40-foot flounder drag conformed with 1953 findings. In May and June, males outnumbered females while in August and September, the sexes were equally represented on the bottom. Larvae are released during the period May to July, with a maximum in mid-June. Surface and oblique plankton tows took maximum catches of larvae in mid-June, demonstrating that female redfish are in the area but off bottom at spawning time. Larvae are dispersed by the Gaspé current; the greatest numbers were taken off Cape Gaspé early June and 30 miles south of this two weeks later.

Diurnal variation in redfish distribution was studied by alternating weeks of afternoon and pre-midnight drags with weeks of post-midnight and morning drags. The smallest catches were consistently made in the pre-midnight period. The largest catches of males were made in morning and afternoon periods. The largest catches of females were made in the post-midnight period. This diurnal variation in distribution of redfish is correlated with diurnal changes in the distribution of *Meganyctiphanes norvegica*, the staple food of redfish in this area. These phosphorescent euphausiids were taken in smallest numbers, by a 40 foot shrimp drag with a one-half inch liner, during the pre-midnight period. Bottom catches of both redfish and *Meganyctiphanes* were progressively smaller at 110, 120 and 130 fathoms.

Autumn redfish cruises have been carried out by the "Investigator II" in the Gulf of St. Lawrence more or less regularly since 1947. The depths investigated were between 120 and 200 fathoms.

The best catches were usually obtained between 140 and 160 fathoms, although there were occasional good catches at 120 and 180 fathoms.

In the early redfish frequencies obtained in the Gulf of St. Lawrence and on the western part of the south coast of Newfoundland by the "Investigator II" in 1947-50, before commercial fishing for redfish had begun in the area, there was evidence from all the deep-water areas of an abundance of large redfish, mostly between 30 and 42 cm. In 1953, after one summer of commercial fishing in the northern areas of the Gulf and several years fishing farther south, these large redfish were still abundant but, as a group, had essentially the same size distribution. In some cases they were slightly more grouped by some growth in the intervening years occurring at the smaller sizes, while there was no evidence of further growth at the upper part of the frequency. The peaks were essentially the same in 1953 as in 1947 and 1948.

While in 1947 and 1950 there was usually only slight evidence of sizes below 30 cm., there

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FRB No. 497C

was in 1953 evidence of a group of redfish with peak sizes between 22 and 25 cm. as well as the larger group in which peak sizes for the males were 34 to 36 cm. and for the females 37 to 38 cm. These two groups of fish were completely separated in the frequency and with the very slow growth of the redfish there is at least a ten year difference in the ages of redfish at the peaks of the two groups. The younger redfish with peak sizes at 22 to 25 cm. were plentiful on the eastern side of the Gulf and on the western part of the south coast of Newfoundland and scarce on the western side of the Gulf, north of Anticosti.

It is evident that, in spite of the redfish being viviparous, and in the absence of mortality of spawning fish through fishing, only rarely is there a good survival of redfish larvae to the settling stage in the Gulf of St. Lawrence or on the western part of the south coast of Newfoundland. In the intervening years there is apparently little or no larval settling. Presumably the redfish in the course of their long larval life in the upper water layers usually drift out of the Gulf.

Cod and haddock tagging. 1954 recoveries from the cod and haddock tagging carried out off southwestern Nova Scotia in 1953 are summarized in Table 3. Recaptures of cod have been high indicating that a high proportion o f the total mortality is attributable to fishing· Recoveries of tagged haddock were surprisingly high in view of the higher tagging mortality for this species. Petersen disk tags gave the best returns.

Table 3

1954 Recoveries from 1953 Cod and Haddock Tagging off southwestern Nova Scotia

Type of Tag	Maximum No. tagged fish Dec. 31/53	No. recovered to Dec. 31/54	% recovery during 1954
	Cod		
Hydrostatic	704	91	13
Red and white disks	191	78	41
Yellow disks	211	70	33
Strap	231	43	19
Total	1,337	282	21
	Haddock		
Hydrostatic	263	30	11
Red and white disks	92	17	18
Yellow disks	79	9	11
Strap	114	11	10
Total	548	67	12

Cod recoveries were, for the most part, from the tagging area. Few winter recoveries were made, although large catches of cod were taken at this season.

Haddock recoveries showed a seasonal movement to offshore grounds. During winter months, the majority of the recaptures were taken on LaHave and Browns Banks.

During 1954, 1,284 cod were tagged o Louisburg and Canso, in eastern Nova Scot and 2,000 cod were tagged along the north sho of the Gulf of St. Lawrence. In both cases th majority of the recaptures taken to date ha come from the tagging area.

Mesh selection. The selective properties large-mesh manila and cotton trawls were studie from the "Pandalus II" and the commerci dragger "Harry G." operating consecutively du ing the period June through August (in the south ern Gulf of St. Lawrence). Cotton three-quart No. 35 and No. 35 Yankee trawls were used b the two draggers. Cod-ends were made of 5 yard, four-ply, double-strand manila or singl strand, Lenco-treated, No. 96 to No. 120 threa cotton. Internal mesh sizes were measured with United States gauge as defined in the Subare 5 haddock mesh regulation. Escapement w measured by using a fine-mesh cover over th cod-end.

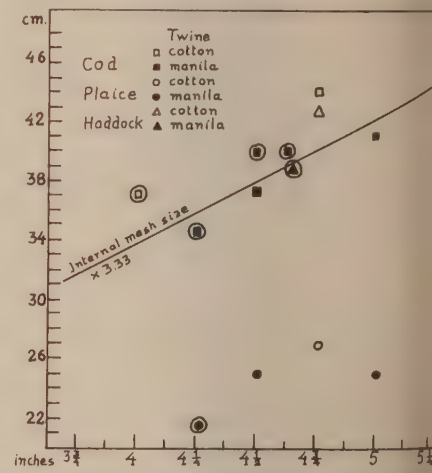

Fig. 3. **Fifty per cent selection points (cm.) fo cod, plaice, and haddock in relation to in ternal mesh size (inches) of cod-end. Cir cled-38 Yankee tr., uncircled-¾ 38 Yankee tr**

The results are shown in Fig. 3. Fifty pe cent selection points for cod taken with manil cod-ends conformed with results for haddock a established in these and earlier experiments Cotton cod-ends released fish at larger sizes tha did manila cod-ends of similar mesh sizes. A expected, the fifty per cent selection points for the plaice, *Hippoglossoides*, were much lower than those for cod and haddock.

The mesh experiments carried out during 1953-54 have demonstrated that the 4½ inch mesh size now used for haddock fishing in Subarea 5 would release large numbers of small cod, had-

ck and plaice in Subarea 4 and practically no
l, haddock, hake (*Urophycis*) or flounders
yptocephalus, *Hippoglossoides*, *Limanda* and
eudopleuronectes) of the sizes landed com-
rcially on the Canadian mainland. Some off-
ore trawlers and Gulf of St. Lawrence draggers
e voluntarily adopting large-mesh nets.

Hook selection. Fishing by hook and line
as important as otter trawl fishing in Subarea 4,
d it is accordingly important to know the selec-
e properties of the various sizes of hooks used
the fishery. Hook selection experiments, car-
d out off Lockeport, N. S., during 1954 demon-
ated that larger hooks take fewer small fish.
our hook sizes were used, No. 17, No. 15, No. 14
d No. 11; No. 17 being the smallest commercial
oundfish hook and No. 11 approximating the
e of a halibut hook. The results for cod are
own in Fig. 4.

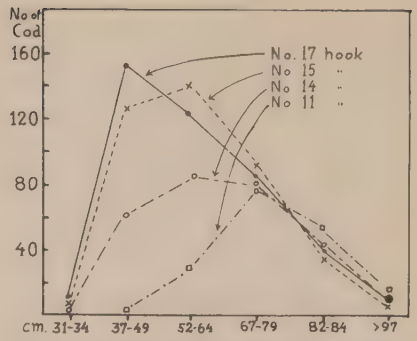

Fig. 4. **Hook selection. Cod. No. of cod caught on hooks of various sizes (nos. 11, 14, 15 and 17).**

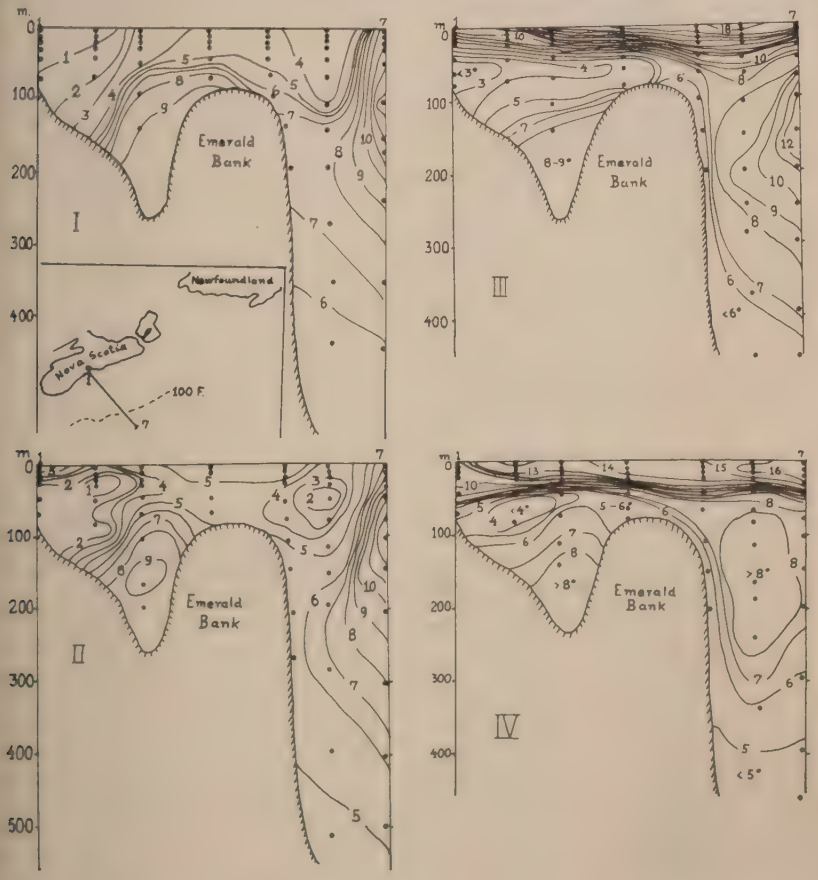

Fig. 5a. **Hydrographic section across the Scotian Shelf off Halifax. Temperature °C. 1954. I-19/20 Feb., II-3 May, III-21/22 Aug., and IV-18/19 Oct.**

The No. 17 hook caught some cod and haddock below acceptable commercial size and was effective in taking all commercial sizes. Available data suggest that selection with the No. 17 hook is comparable with that of a 4½ inch mesh. The No. 11 hook caught few haddock and few small cod in comparison with the No. 17 hook. The No. 15 and No. 14 hooks showed intermediate selection.

If a mesh size greater than 4½ inches is considered for conservation purposes, consideration must also be given to hook selection.

Fish eggs and larvae. The first of planned seasonal and annual samplings of Bay of Fundy, Scotian Shelf and Gulf of St. Lawrence waters was completed during August and September. Concentrations of larvae were found in Magdalen Shallows and on offshore banks to the northeast and southwest of Nova Scotia. Eggs were concentrated inshore off southwest Nova Scotia, off northeastern Cape Breton Island and on Quere Bank. Cod larvae were taken in quantity Magdalen Shallows, haddock off southwest No Scotia, and redfish off southwest Nova Scot on Quereau Bank and in the southern Gulf of Lawrence.

Hydrography. As a continuation of a lo term program of seasonal surveys initiated 1950, the Atlantic Oceanographic Group carr out four seasonal cruises in the Bay of Fun Scotian Shelf, and the Gulf of St. Lawrence are The winter cruise was extended to the head of t Bay of Fundy and included a large coverage of t area between Brown's Bank and the coast Maine. During the summer survey, plankt tows were taken at strategic points and the Har Plankton recorder was used most of the ti over the Scotian Shelf and in the Gulf of Lawrence. The quarterly section off Halifax shown in Fig. 5.

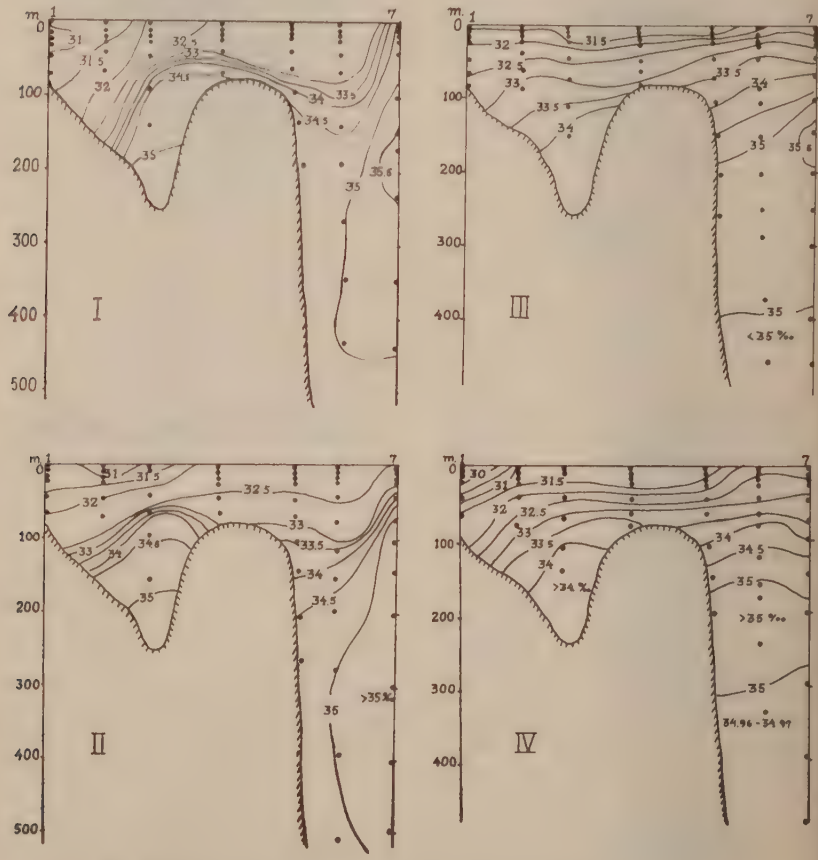

Fig. 5b. Hydrographic section across the Scotian Shelf off Halifax. Salinity °/₀₀.

Further study of the bottom temperatures the Scotian Shelf has been made in comparing data obtained between 1950 and 1953 with se from earlier surveys made over a somewhat re restricted network between 1934 and 1939. general, bottom temperatures have tended to higher during the recent period than they e prior to 1939, by as much as from one to ee °C in the eastern sector and from two to ee on LaHave Bank. It would appear that main reasons for the variations in bottom perature over the Scotian Shelf have been nges in the intermediate layer which was ier and thicker in the early years than it has since 1950.

Analysis of the long term temperature re- ds of surface waters at St. Andrews, N. B., Sambro L. V. off Halifax, N. S., has shown arked correlation between the annual mean perature in any year and the amount of ling taking place in the previous winter. Low annual mean temperatures have followed periods of intense cooling during the previous winter and high annual means have been related to lack of cooling rather than to excessive warming in summer. Annual means can be predicted by March with a fair degree of accuracy.

The data obtained from continued observations of surface water temperatures at strategic points along the Canadian Atlantic coast have shown that, in 1954, the annual means were equal to or higher than the average during the preceding five-year period. In the southwestern Gulf of St. Lawrence, the 1954 mean was lower than the average of the preceding quinquenniad.

In the oceanographic surveys of the waters around the Gaspé peninsula and along the north shore of the Gulf of St. Lawrence, emphasis was given to fishing areas such as Bay Chaleur, Miscou and Orphan Banks and fishing banks along the north shore.

eprinted from pages 21-23 of the Annual Proceedings, International
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lifax, N.S., Canada, 1956.)

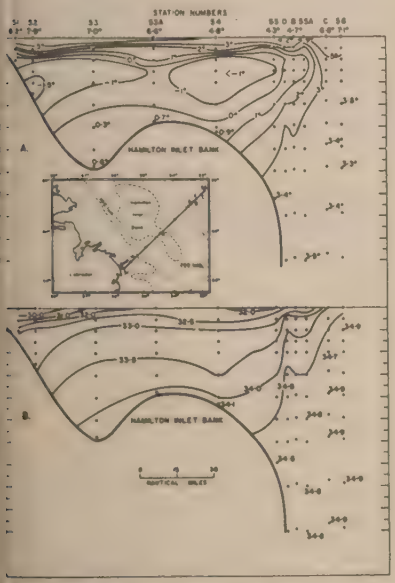
I. Canadian Researches, 1955

SUBAREA 2. By W. TEMPLEMAN[1]

No groundfish investigations apart from rography were carried out in Subarea 2 in 1955.

Hydrography. An attempt was made in July to take the two sections off northern central Labrador which were last taken by *Investigator* II in 1950, but the area was ered with floe ice and the stations could not occupied.

The section across the Labrador current inning off Seal Islands and extending across Hamilton Inlet Bank area and shown in 1 was taken by the *Investigator* II in July-ust. In this section there was a much smaller me of water below -1°C. and below 0°C. 955 than in 1954.



1. **Hydrographic section off Seal Islands-Hamilton Inlet Bank, Labrador, July 31-August 1, 1955; A—Temperature °C.; B—Salinity °/₀₀.**

SUBAREA 3. By W. TEMPLEMAN

The sampling, for size and age, of the commercial catch of the important groundfish species both offshore and inshore was continued at Bonavista, St. John's, Burin, Fortune, Ramea and Isle aux Morts. Location of catch and effort statistics were collected for the offshore vessels.

Haddock *Melanogrammus aeglefinus* (L.). The annual haddock survey on the Newfoundland Banks was carried out by the "Investigator II" in May and June. The 1949 year-class of haddock continued to predominate in the commercial sizes. This year-class and the total of all year classes of haddock were most numerous at 41 centimetres on the Grand Bank and at 42 centimetres on the St. Pierre Bank. On the Grand Bank, haddock of the 1952 year-class with a modal size at 31 centimetres were plentiful on the southeastern part where also moderate numbers of the 1953 year-class with a modal size of 25 centimetres were present. Both these year-classes were considerably less plentiful in the southwestern portion of the bank. Only a few one-year-old haddock were obtained.

On the St. Pierre Bank haddock younger than the 1949 year-class were not found in significant numbers.

During the haddock survey on the Grand Bank between May 17 and June 18 the haddock had moved from the deeper water where they had spent the winter, and were most numerous at 30 to 40 fathoms. The haddock were in greatest numbers in temperatures of 7 to 3°C. and the cod in temperatures below 2°C.

In research-vessel catches on the Grand Bank the year-class distribution of 617 haddock was: 1953 year-class 6%; 1952, 20%; 1949, 66%; 1946, 3%. Other year-classes were 1% or less. On St. Pierre Bank for 115 haddock, 90% belonged to the 1949 year-class and other year-classes were 2% or less.

Most of the Canadian haddock catch in the area was landed in the round condition.

Tagging and Migrations. On the Virgin Rocks of the Grand Bank, 1,570 cod, *Gadus*

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. John's, Nfld.

FRB No. 497D

callarias L. were tagged, and 500 cod were tagged on the Southeast Shoal of the Grand Bank.

From the cod tagging on Burgeo Bank in 1954 there has been migration to the neighbouring coastal areas and some to the Gulf of St. Lawrence and to the eastern part of the South coast of Newfoundland and St. Pierre Bank. There were no recaptures from the Grand Bank.

Cod tagged on the northern plateau of St. Pierre Bank, 1954, were recaptured mainly near the tagging area and in the southeastern coastal area of Newfoundland. Only about 1% have been recaptured on the Grand Bank and none in the Gulf of St. Lawrence or on the northeast coast of Newfoundland.

Cod tagged at St. Anthony and La Scie in 1954 have migrated along the coast northward toward southern Labrador and southward as far as Cape Race. Of several hundred recaptures from each tagging area, not one St. Anthony cod and only one La Scie cod has been recaptured in the Grand Bank-St. Pierre Bank area.

Cod tagged at Bonavista in 1954 have spread north and southwards along the east coast of Newfoundland. The four bank recaptures (out of 120 recaptures) were all taken on the northern slope of the Grand Bank.

Cod tagged in 1954 at Fermeuse and at Cape Pine and Cape St. Mary's on the Avalon Peninsula show a much greater relation to the banks than do the northern cod. Out of about 400 recaptures, 76 recaptures have come from the bank areas including 52 from the Grand Bank, 19 from St. Pierre and Green Bank, 1 from Burgeo Bank and 4 from Banquereau.

Of 499 American plaice, *Hippoglossoides platessoides* (Fabr.), tagged in St. Mary's Bay in June and September, 1954, only one has been recaptured; in November 1955, inshore off the middle of the eastern side of the Avalon Peninsula, a distance of about 65 nautical miles from the point of tagging. From 1,000 American plaice tagged near the northern tip of the Grand Bank in October, 1954, there were 26 recaptures in 1955, all, except one, near the point of tagging. The one exception was caught on the northeastern part of the bank about 130 nautical miles from the tagging area.

Redfish, *Sebastes marinus* (L.). During the year, the redfish population in Hermitage Bay was sampled bi-monthly by the "*Marinus*."

In Hermitage Bay at the present time the redfish length frequency curve is typically trimodal. The peaks are well separated indicating only occasionally successful years for larval survival. By means of a cover of ½ inch nylon or ¾ inch cotton over the codend a numerous group of small redfish has been captured, well separated in length from larger fish. This gro can thus be followed independently of a readings, and has shown the following avera total lengths (from the anterior tip of the lo jaw with the mouth closed to the mid-point the fork of the caudal fin).

1953	December	—	7.1 c
1954	June	—	8.1 c
1954	September	—	8.8 c
1954	December	—	9.0 c
1955	April	—	9.6 c
1955	June	—	10.6 c
1955	August	—	11.3 c
1955	Oct.-Nov.	—	11.8 c

A preliminary study of the scales and otoli of these fish shows that at least 90% of the f forming the above group were of the same ye class. These fish with scale ages showing incomplete first year in December, 1953, show 1+ years in December, 1954, and 2+ dur August, 1955. In hundreds of sets, betwe December, 1953, and December, 1955, only th redfish were caught of a definitely more rec year-class.

The O+ scale age-group first caught in 19 was probably of the 1952 or the 1951 year-cl since the scales of redfish are unlikely to app in their first year.

Hydrography. In April the usual hyd graphic sections on the southern part of Grand Bank and on St. Pierre Bank were occup by the "Investigator II."

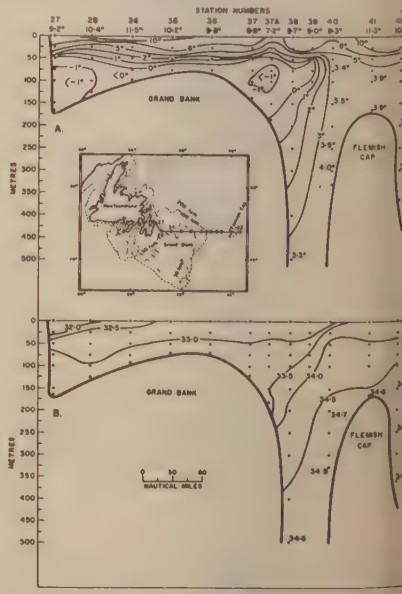

Fig. 2. Hydrographic section, St. John's-Gra Bank-Flemish Cap; July 20-25, 195 A—Temperature °C.; B—Salinity °/₀₀.

In July and August five hydrographic sec-
s were taken from Bonavista to the southern
e of the Grand Bank. Compared with the
l section there was less water below -1°C.
he Bonavista section and the lowest tempera-
s were not as low. In the St. John's to
nish Cap section (Fig. 2) temperatures below
. in the Avalon Channel were not as low as in
l but to the east and also immediately north
he Grand Bank there was more water below
. and especially on the north fringe of the bank
h more below 2°C. On the southwest slope
he Grand Bank there was much more cold water from the eastern branch of the Labrador Current extending westward along the southwest slope than in 1954, reflecting the greater amounts of cold water found on the northern parts of the bank.

Bottom temperatures in August were higher on the central part of the bank and lower on the southern part of the bank than in April.

The inshore upper warm-water layer did not remain as stable and as shallow throughout the summer as in 1954, and the inshore cod, though fairly abundant, were not so abundantly available in shallow water over so long a period as in 1954.

printed from pages 23-27 of the Annual Proceedings, International
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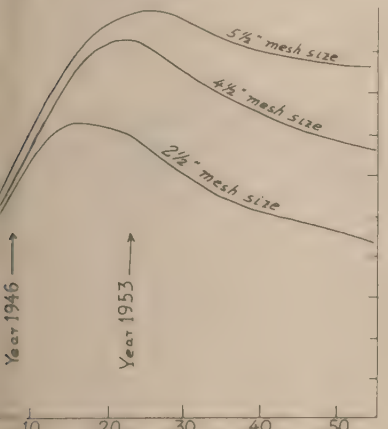
.ifax, N.S., Canada, 1956.)

Canadian Researches, 1955

SUBAREA 4. By W. R. MARTIN[1]

Cod. A population dynamics study of cod Subdivision 4T has shown that the post-war ersion from line fishing to otter trawling has rsely affected the fish stocks. The sizes of caught are below the optimum for maximum ings. The best size for first capture has been ulated to be about 1½ kilograms. round ht. The study has shown that even with -mesh nets, the present intensity of fishing fficiently high for best use of the resource Fig. 3).



3. Cod, Gulf of St. Lawrence, Subdivision 4T off Northern New Brunswick. Y=yield in 1000 pounds from 10,000 half pound cod. F.=Instantaneous fishing mortality (fishing intensity). Natural mortality assumed to be .12.

Cod tagging was continued in the Bay of eur region of the Gulf of St. Lawrence. n June to September, 1955, 3,851 cod were ed in this area. The tagging was done from 55 foot M.B. *Mallotus*, and most of the fish agging were caught by handline. Recoveries ng 1955 are compared with recoveries from r cod taggings in Table 1. The percentage ags recovered was relatively small, and cod red more movement than in other areas.

These tagging data are providing useful information on discreteness of stocks, growth rates and fishing mortality rates of cod.

Haddock otoliths. During 1955, the validity of the otolith method of aging Subarea 4 haddock was studied. Annual formation of one hyaline and one opaque zone was found in haddock otoliths sampled during the period 1947 to 1954. Dominant year-classes did not lose their relative importance, compared with adjacent year-classes, as they passed through the fishery. Fish from length modes, sampled as the modes moved along the length distribution scale, added one annulus per year to their otoliths. For these reasons, the majority of haddock-otolith age determinations were believed to be correct.

Mesh selection. The selective properties of cotton and nylon meshes were compared with those of manila meshes. The results of these studies are shown in Fig. 4. Nylon meshes allow

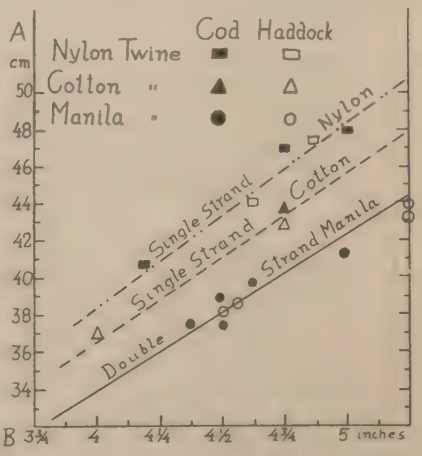


Fig. 4. Comparison of 50% selection points for cod and haddock with codends of manila, cotton and nylon strands. A—50% selection point. B—internal mesh size.

ad of Groundfish Investigation, Fisheries Research Board of
ada, Biological Station, St. Andrews, N.B.

TABLE 1—SUBAREA 4 COD TAGGING EXPERIMENTS—1953 to 1955

	Number Tagged	Recovered to Dec. 31/53	Recovered Jan. 1— Dec. 31/54	Recovered Jan. 1— Dec. 31/55	Total Recovered Dec. 31
1953 Lockeport—4X inshore					
Lea Hydrostatic	933	229 (25%)	91	4	324 (35%
Yellow Petersen Disk	303	92 (30%)	70	5	167 (55%
Red and White Petersen Disk	305	114 (37%)	78	7	199 (65%
Monel Metal Strap	263	32 (12%)	43	3	78 (30%
TOTAL	1,804	467 (26%)	282	19	768 (43%
1954 Canso—4W inshore					
Lea Hydrostatic	175		45 (26%)	18	63 (36%
Yellow Petersen Disk	178		49 (28%)	37	86 (48%
Red and White Petersen Disk	121		27 (22%)	28	55 (45%
TOTAL	474		121 (26%)	83	204 (43%
1954 Louisbourg—4V inshore					
Lea Hydrostatic	318		42 (13%)	39	81 (25%
Yellow Petersen Disk	298		52 (17%)	49	101 (34%
Red and White Petersen Disk	194		51 (26%)	32	83 (43%
TOTAL	810		145 (18%)	120	265 (33%
1955 Caraquet—4T inshore					
Lea Hydrostatic	1,206			78 (6%)	
Yellow Petersen Disk	2,645			160 (6%)	
TOTAL	3,851			238 (6%)	

cod and haddock of a larger size to escape than do cotton or manila meshes of the same internal size. Cotton in turn allows larger fish to escape than manila. For the purpose of releasing small cod and haddock, a 4½ inch mesh manila codend is about equivalent to a 4¼ inch mesh cotton and a 4 inch mesh nylon codend.

The effect of "chafing gear" (the protective material on top of some codends) on the release of small haddock was studied. When attached loosely, as specified in ICNAF mesh regulations, "chafing gear" did not affect the 50% selection point of a largemesh codend. When attached tightly, "chafing gear" reduced the 50% selection point by 3 to 4 centimetres.

Redfish. Growth and maturity of Subdivision 4T redfish were studied. Female redfish were found to grow faster, mature at a larger size (25-30 cm.), and attain a larger size than male redfish. The modal lengths of males were 35 to 36 centimetres and of females 38 to 40 centimetres. Gulf of Maine redfish are reported to mature at a smaller size and reach a smaller adult size. On the other hand, European *Sebastes marinus* are reported to mature at a much larger size and attain a much larger adult size. Maximum releases of larvae in June was also found to be intermediate between Gulf of Maine (July) and northern Europe (May).

Halibut, *Hippoglossus hippoglossus* (L.). Statistics of halibut landings were reviewed. The greatest landings have been made by the Canadian offshore fleet. Vessels fishing for h but contributed the greatest share of these shore landings and most of the fish were "mediu and "large" (over 6 kg.). Otter trawlers dory vessels fishing other species in the shal water of the same regions, took only a su portion of the total weight landed, but a la proportion of the total number of halibut land Growth of the small halibut was believed to m than compensate for their natural mortal It may be possible to increase halibut landi by reducing the catches of small halibut.

Fish eggs and larvae. Analyses of col tions from five cruises made during 1955 h not been completed. Distribution and abu ance of planktons showed four major areas production south of the Laurentian Chan (a) off southwestern Nova Scotia, (b) off nor eastern Nova Scotia, (c) southern Gulf of Lawrence, and (d) northwestern Gulf of Lawrence. High plankton productivity wo seem to be related to the bank areas. Sum plankton including young fish were scarce in 1 as compared with relatively large quanti present at the same time in 1954.

Hydrography. The Atlantic Oceanog phic Group continued to make seasonal surv of the Bay of Fundy, Scotian Shelf and the G

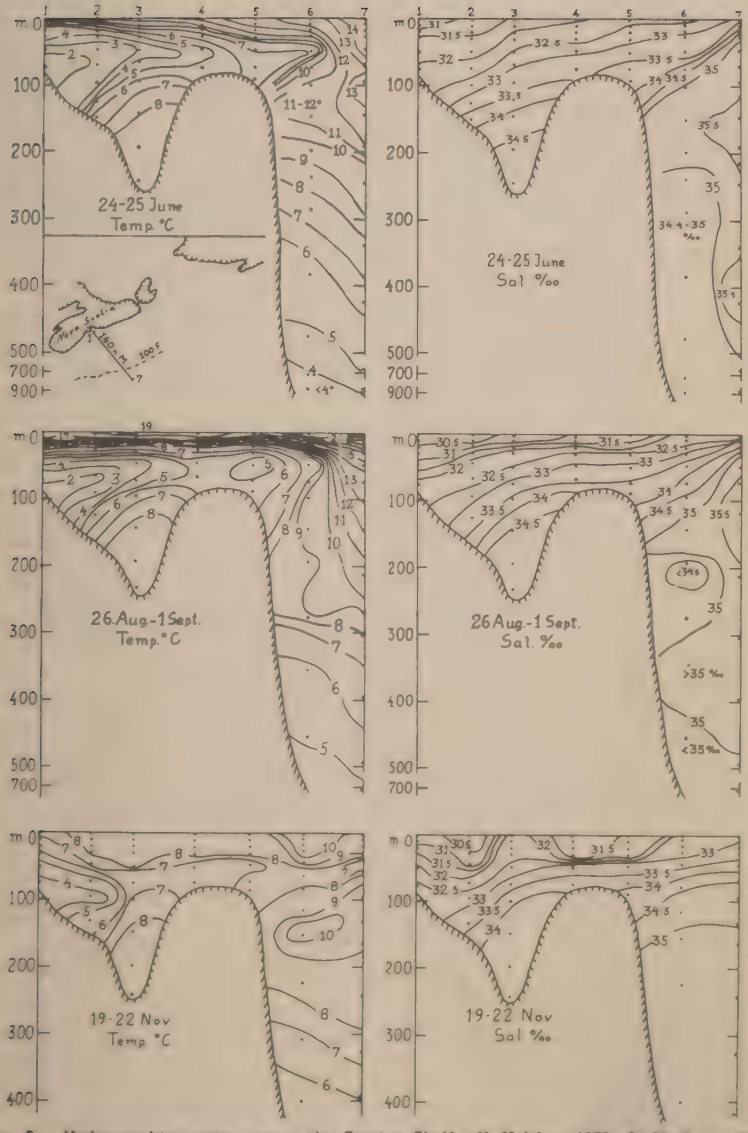


Fig. 5 Hydrographic section across the Scotian Shelf off Halifax, 1955, 24-25 June, 26 Aug.-1 Sept. and 19-22 Nov. Left—temperature, right—salinity.

of St. Lawrence areas. Three cruises were made in 1955. The early summer survey was extended to the estuary of the St. Lawrence. The hydrographic section off Halifax is described in Fig. 5. The surface layer was much warmer and less saline than in the summer of 1954, especially near the coast. The minimum temperature in the cold-water layer was lower in 1955 than in 1954.

Analysis of surface water temperatures at six points along the coast revealed a general decrease in 1955 as compared to the previous year. Short-term forecasting of annual mean surface water temperatures at St. Andrews, N. B., may now be done with some reliability. It is predicted that the mean temperature will decr again in 1956. With some reservation. downward trend from peak temperatures in applies to Subarea 4 generally.

Currents and volume transport have calculated by dynamical methods for Ca Strait from data collected through the years 19 54. Great variations were found: currents w strongest in August and least in April and M Currents were outward on the Cape Breton and inward on the Newfoundland side.

Analysis of bottom temperatures on Magdalen shallows (Subdivision 4T) shows seasonal variation in bottom temperature controlled by stratification. The thickness of intermediate cold layer is of primary importa

(Reprinted from Annual Proceedings, Vol. 7, International Commission for the Northwest Atlantic Fisheries, pp. 21 to 27, 1957.)

PART 3

Summaries of Research 1956

A. Summaries by Countries

I. Canadian Researches, 1956

SUBAREA 2. By W. TEMPLEMAN

Examination of samples of redfish, from depths of from 150 to 300 fathoms, east of Hamilton Inlet Bank, Labrador, showed that only a very few very large common redfish, *Sebastes marinus marinus* (L.), were present while over 99% of the redfish were of the deep-water type *Sebastes marinus mentella* Travin.

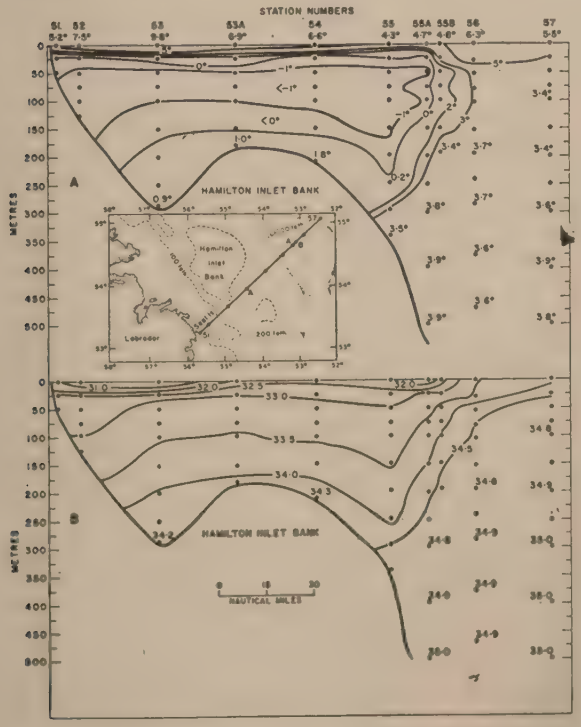


Fig. 1. Hydrographic section off Seal Islands, Labrador, August 4-6, 1956 (A—Temperature °C; B—Salinity °/₀₀.

The customary hydrographic section from near shore off Seal Islands, Labrador, to beyond the 500 metre line, east of Hamilton Inlet Bank, was taken by the *Investigator II*, August 4 to 6, 1956 (Fig. 1).

Temperatures in the upper warmer layer and in the intermediate cold layer were very similar to those of 1955. The volumes of water with temperatures below -1°C. and below 0°C. were similar inshore but offshore this cold water was a little greater in volume and extended more deeply in 1956 than in 1955. Bottom temperatures and temperatures in the offshore deep water, on the other hand, were higher (usually about 0.3°C.) than in 1955. Salinities were very similar to those of 1955.

SUBAREA 3. By W. TEMPLEMAN

The Fisheries Research Board continued to gather information on the location of catches and on catch per unit effort by the offshore groundfish fleet. The offshore commercial catches of groundfish were sampled for size and age, and the inshore cod catches were similarly sampled at Bonavista, St. John's and Burin.

Haddock *Melanogrammus aeglefinus* (L.). An otter-trawl survey for haddock and cod was carried out by the *Investigator II* on the Grand Bank in April and May and on St. Pierre Bank in early June. A few good haddock catches were made on the Grand Bank but only very small catches of haddock were obtained on St. Pierre Bank. On St. Pierre Bank there was excellent haddock fishing during the winter and early spring of 1956 when the fish were concentrated in deep water below 100 fathoms. By June the fish had apparently spread from the deep water over a great part of the bank area and were not found in commercial quantities by the research vessel either in June or in a later survey carried out in October. Also, except for occasional sporadic catches, there was very little commercial fishing for haddock on St. Pierre Bank in 1956 after the winter and early spring. The very numerous 1949 year-class, on which the fishery has depended since the autumn of 1953, evidently has become too scarce to sustain an extensive fishery.

On the Grand Bank the numerous 1949 year-class provided almost all the haddock of commercial size, and two fairly numerous year-classes

1952 and 1953, were approaching commercial size. Although the years 1950, 1951 and 1954 produced no significant survival of young haddock, there was evidently good survival of the 1955 year-class.

On St. Pierre Bank almost all the haddock of commercial size were from the 1949 year-class. There was no evidence of significant survival of young haddock of the 1950 to 1954 year-classes but there was a fairly good survival of the 1955 year-class. In the further survey of St. Pierre Bank in October there was preliminary evidence, also, of a good survival of the 1956 year-class of haddock. The 1955 year-class will not produce significant quantities of commercial fish before the autumn of 1959 or the spring of 1960.

Redfish *Sebastes marinus* (L.). Deep-water dragging. The *Investigator II* carried out deep-water explorations for redfish at depths from 100 to 400 fathoms north of Flemish Cap and off the southwest Grand Bank. A No. 3/4 35 otter-trawl with a 39-foot headrope and a 50-foot footrope, and with otter doors of 400 pounds each, was used on a single wire. North of Flemish Cap the average redfish catches per half-hour's dragging were as follows:

100	fathoms	—	0 lb.
150	,,	—	150 ,,
200	,,	—	700 ,,
250	,,	—	1300 ,,
300	,,	—	500 ,,
350	,,	—	100 ,,
400	,,	—	0 ,,

These were only half-hour drags with a very small net and with the inefficient single-wire type of fishing. The redfish were of moderate commercial size, the bottom was smooth, and it is indicated that good commercial fishing possibilities exist between 200 and 250 fathoms in this newly explored area.

On the southern part of the southwest slope of the Grand Bank the average catches of redfish per half-hour's dragging were as follows:

100	fathoms	—	1170 lb.
150	,,	—	890 ,,
200	,,	—	920 ,,
250	,,	—	640 ,,
300	,,	—	190 ,,
315-360	,,	—	20 ,,

In this area sizes increased with increasing depth.

Two subspecies. In 1956, for the first time, our biologists have observed that two varieties of redfish, *Sebastes marinus marinus* and *Sebastes marinus mentella*, are present in the Newfoundland area. The scarcer *marinus* type is usually orange yellow or golden yellow, possesses no beak or a rounded beak on the chin, has small eyes, and is different from *mentella* in a number of body proportions. The deep-water or *mentella* type is usually red to deep red, possesses a sharp and in older specimens often a long chin beak and has relatively large eyes. These, and other distinctions between the two forms, were noted in June in Hermitage Bay and in July at Flemish Cap. The *marinus* form was the shallower and the *mentella* form the deeper and by far the more abundant; the commercial fishery in the subarea depends almost entirely on the *mentella* form. In the European and Icelandic area, on the other hand, *marinus* appears to be the more usual type in the commercial fishery. At Flemish Cap the *marinus* form was more abundant than the *mentella* in the small numbers of redfish secured at 150 fathoms. At 200 fathoms most of the redfish were *mentella* and a few, all the largest specimens, 43 to 53 cm. were *marinus*. At 250 fathoms, where the best catches were obtained, all were *mentella*, and at 300 fathoms all were very typical *mentella*. In Hermitage Bay, Newfoundland, only an occasional *marinus* type is present among the very numerous *mentella*. No evidence of *marinus* was found in redfish catches on the southwest slope of the Grand Bank, but some are present south of Green Bank.

Other studies of redfish. Studies are being carried out on sexual maturity, fertilization and spawning, and on body proportions of redfish from various localities. Preliminary tagging experiments have been done, and researches on age and growth, ecology, food, and on other features of redfish life history have been continued.

Flatfishes. Research has been renewed on the American plaice, *Hippoglossoides platessoides* (Fabr.) and the witch flounder, *Glyptocephalus cynoglossus* (L.). The present effort, which began in May for the plaice and in August for the witch flounder, has been concerned mainly with age and growth studies.

From the tagging of 1,000 plaice on the northern Grand Bank in October, 1954, 26 were recovered in 1955 and 4 in 1956. Most of these were

recaptured within a radius of about 30 miles from the tagging site. The greatest migration was by a fish recaptured in October, 1955, on the eastern slope of the Grand Bank, 120 miles from the tagging area.

There has been some new work on body proportions of plaice in different areas. It is planned to extend the scope of the flatfish work in 1957.

Cod *Gadus callarias* L. Cod investigations were devoted mainly to age and growth and other population studies. In the otter-trawling surveys of the *Investigator II* on the southern half of the Grand Bank the first four age groups of cod could be recognized from the length frequencies alone. This will allow an excellent check on age determination in this southern Grand Bank area for which age reading in cod is difficult.

Plankton. Zooplankton was collected on hydrographic cruise 34 of the CNAV *Sackville* during September 15 to 30, 1956. Vertical tows were made with a 3/4 metre net (No. 10 mesh) from a depth of 50 metres. Generally, high zooplankton production (to 40 cc./20 m3) was shown near Cabot Strait, over the Grand Banks and in Trinity Bay; and very low production over the Laurentian Channel, south of the banks, near the Newfoundland south coast and off Trinity Bay. Fish larvae included capelin at four stations on the Grand Bank and six stations in Trinity Bay, and American plaice, witch flounder, Greenland halibut, *Reinhardtius hippoglossoides* (Walb.) and silver hake, *Merluccius bilinearis* (Mitch.) in Trinity Bay, mostly taken in oblique tows with a high-speed all metal plankton sampler.

Hydrography. In July and August the regular five sections were taken from Bonavista to the southern slope of the Grand Bank. In addition once or twice a month throughout the year the station 5 miles off Cape Spear, in 176 metres was occupied. Daily surface temperatures were taken in St. John's harbour. Considering the whole water column down to 500 metres, temperatures were not greatly different from those of 1955.

In the Flemish Cap section, July 25-August 1 (Fig. 2), the volume of water below -1°C. was approximately the same as in 1955 and the volume below 0°C. slightly less. The top of the Grand Bank was covered with slightly warmer water and there was also a greater volume, than in 1955, of

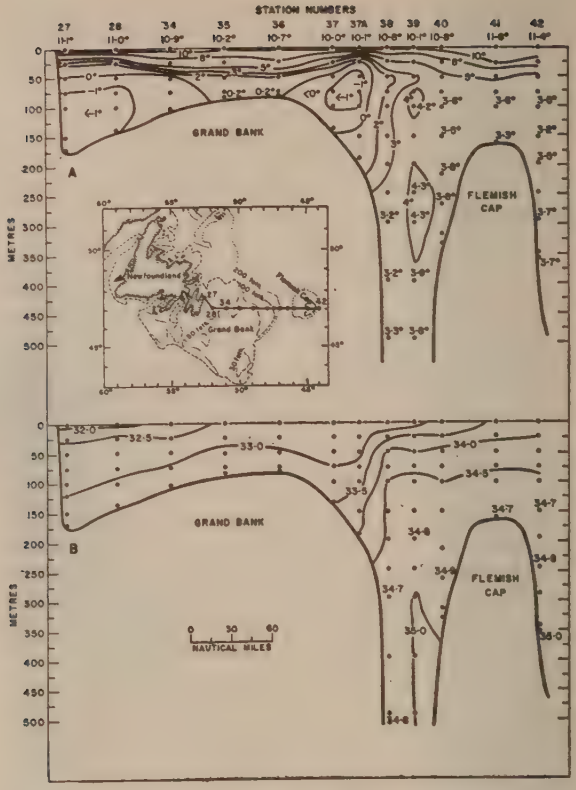


Fig. 2. **Hydrographic section, St. John's-Grand Bank-Flemish Cap, July 25-August 1, 1956; A-Temperature °C; B—Salinity °/₀₀.**

water above 3°C. in the channel between the Grand Bank and Flemish Cap. Salinities also were significantly higher than in 1955 in the Grand Bank-Flemish Cap channel.

SUBAREA 4. By W. R. MARTIN

Tagging. Cod, *Gadus callarias* L., and haddock, *Melanogrammus aeglefinus* (L.), were tagged in Subdivision 4T during 1956 to provide additional information about movements, mixing of stocks, growth, and the proportion of stocks being taken by the fisheries. Otter-trawl caught fish were tagged for the first time in this area. In May, 733 cod were tagged off northern Cape Breton in 40 to 100 fathoms. In July and August, 1775 cod were tagged off northern New Brunswick in 30 to 50 fathoms. In September and October, 994 haddock were tagged in the eastern Northumberland Strait region in 20 to 30 fathoms.

A large proportion of the tags attached to cod and haddock in the years 1953 to 1955 have been recovered. Disk tags have given higher returns than hydrostatic tags. The high percentages of recaptures from inshore Nova Scotia taggings (50 to 60% for disk-tagged cod and 37% for disk-tagged haddock) demonstrate that the fishery takes a high proportion of the stocks on these grounds. The lower percentage recovery from Gulf of St. Lawrence cod tagging is consistent with the lower total mortality there, as determined from age analyses.

Cod tagged in the Gulf of St. Lawrence moved about more than those of inshore Nova Scotia waters. Tag returns have shown that the Gulf stocks support two main fisheries: one in the western Gulf of St. Lawrence during summer by Canada, the other in the Cabot Strait area in winter mainly by European fleets.

Preliminary results of haddock tagging in the southern Gulf of St. Lawrence indicate a similar seasonal movement out of the Gulf in the autumn to Nova Scotia grounds.

Haddock Ageing. Canada and the United States continued their joint study of haddock age reading. Age determinations for 973 haddock revealed differences between scales and otoliths. Disagreement in age readings per sample increased with increasing age and averaged 40%. In general, disagreements were randomly spread up to 8 years. However, above 8 years the otolith age readings were a year or more higher than the corresponding scale readings. Independent estimates of growth from tagging supported earlier conclusions that the use of haddock otoliths is valid for age determinations. Canadian and U.S. biologists have now agreed to use the otolith method for ageing Subarea 4 haddock.

High Cod Landings. In 1956 cod fishing in Subdivision 4T was exceptionally good (Fig. 3). Landings of cod in the provinces of Quebec, New Brunswick and Prince Edward Island totalled 118 million pounds, gutted weight, the largest landings on record. Individual as well as total catches were large. The average landings per week for "Gloucester" class draggers increased from 21 thousand pounds in 1955 to 27 thousand pounds in 1956.

The cod landed by draggers at Caraquet, N. B., were considerably larger (average weight

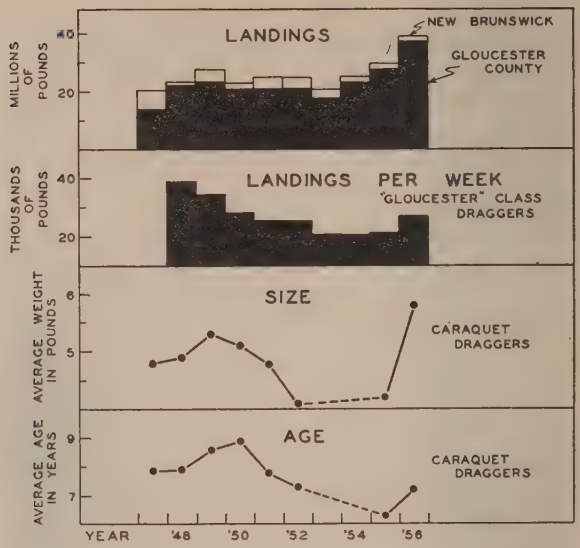


Fig. 3. **Annual variation in landings, landings per week, sizes and ages of cod landed, in northern New Brunswick from Subdivision 4T during the years 1947-56.**

5.8 lb.) than those landed in 1955 (average weight 4.2 lb.) and the average age increased from 6.3 years in 1955 to 7.2 years in 1956.

The growth rate of these cod was much higher in 1955-56 than in the period 1947-52. This was particularly true for the larger fish-eating cod. Seven to nine-year-old fish were about 2 pounds heavier than formerly. It appeared that the faster growth was brought about by the increased availability of moribund herring during an epidemic of fungus disease (*Ichthyosporidium hoferi*). Reduced density of cod also may have contributed to the increased growth rate.

The landings of Gulf cod did not increase in numbers in 1956, but the larger sizes of cod produced a substantial increase in landings by weight.

Discarded Cod. Seven trips on commercial draggers in the southern Gulf of St. Lawrence (Subdivision 4T) provided data on the sizes and numbers of cod discarded at sea (Fig. 4). Three-inch mesh manila nets were used. Small draggers of about 25 gross tons working in 20 to 45 fathoms of water discarded 55% by number and 14% by weight. Larger draggers of about 40 tons working on larger fish in 30 to 125 fathoms

discarded 18% by number and 4% by weight of the fish caught. The 4½-inch mesh now required by regulation would have reduced the numbers of cod discarded at sea in 1956 by about half. In order to reduce the observed wastage of cod to a minimum, the mesh size would have to be about 5½ inches, inside, stretched, wet, used measure.

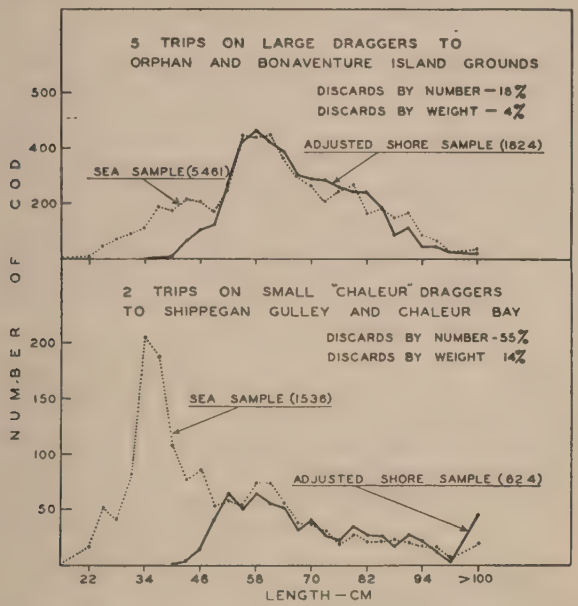


Fig. 4. **Numbers and sizes of cod caught and landed by commercial draggers fishing from northern New Brunswick ports in Subdivision 4T during the period 30 May to 5 September, 1956. Shore sample adjusted to give equal numbers of cod to sea sample above 49cm.**

Mesh Selections. Three experimental trips on commercial otter trawlers during 1956 provided information which is pertinent to the implementation of mesh regulation in Subarea 4:

(1) Tests have shown that a short piece of "chafing gear" on top of the codend, when applied as specified by ICNAF recommendations, does not reduce the escapement of haddock and cod through a large-mesh codend. However, a long piece of chafing gear does reduce escapement.

(2) The use of double codends greatly reduced the sizes and numbers of small fish which would escape from a single codend of the same mesh size. The results showed that additional strength in codends should be obtained from increased size or strength of twine rather than from double codends if mesh selection is to be effective (in releasing small fish).

(3) Field studies with double-strand, 80-yard, braided nylon codends showed that a mesh size of $4\frac{3}{8}$ inches was equivalent to $4\frac{1}{2}$-inch manila in releasing fish. In these studies the sizes of haddock released from the codends were smaller than the sizes of cod released from the same codends (selection factors—3.8 for cod and 3.3 for haddock.).

(4) The suitability of large-mesh manila codends for incidental redfish catches was tested in the Gulf of St. Lawrence. A $4\frac{1}{2}$-inch mesh codend released about 50% of the 28 cm. redfish. With this large-mesh codend a very small proportion of the sizes of redfish now landed in Canada were released, and meshing of redfish was less serious than generally predicted.

Plankton. Analyses of plankton studies carried out in 1954 and 1955 showed that both seasonally and annually, in surface waters, heavy zooplankton concentrations (900 c.c. per tow) were associated with low temperatures (9-14°C.) and light concentrations (200 c.c. per tow) with high temperatures (17-19°C.).

Hydrography. The long-term program of seasonal surveys, initiated in 1950, covering a network on the Scotian Shelf, the entrance to the Bay of Fundy, and the Gulf of St. Lawrence has been continued by the Atlantic Oceanographic Group. The section off Halifax, N. S., was surveyed three times (Fig. 5, attached). The surface layer was colder in the summer 1956 by an average of 2°C. The minimum temperature in the cold-water layer was lower in 1956 than in 1955 by an average of 0.5°C.

At shore stations, continued observations of surface water temperatures revealed a general decrease in 1956 as compared to the previous year. It was the third consecutive year of general cooling.

The circulation pattern on the Scotian Shelf based on temperature and salinity observations since 1950, shows certain persistent features. The net flow is always found to be southwesterly around Cape Breton varying in magnitude seasonally, from a minimum in the early spring to a maximum during the summer months. The flow is normally to the southwest all along the Atlantic Coast of Nova Scotia, until it reaches Cape Sable. In this area, the flow is evidently divergent with part moving northward towards the Bay of Fundy and part moving southward. The region of divergence appears to fluctuate somewhat in in position with volume transport proportions in each branch varying markedly.

Observations in the central Gulf of St. Lawrence, during the summer, have shown that the Gaspé Current is in part continuous along the southern edge of the Laurentian Channel as far as Cabot Strait. Another portion spreads out over the Magdalen Shallows.

A reasonable correlation has been found between the ratio of haddock to cod landings in ICNAF Subarea 4 and a reliable index of water temperatures over the area. This is in agreement with the known difference in temperature preferences of the two species. This relationship may be of use in forecasting groundfish landings on the basis of temperature trends.

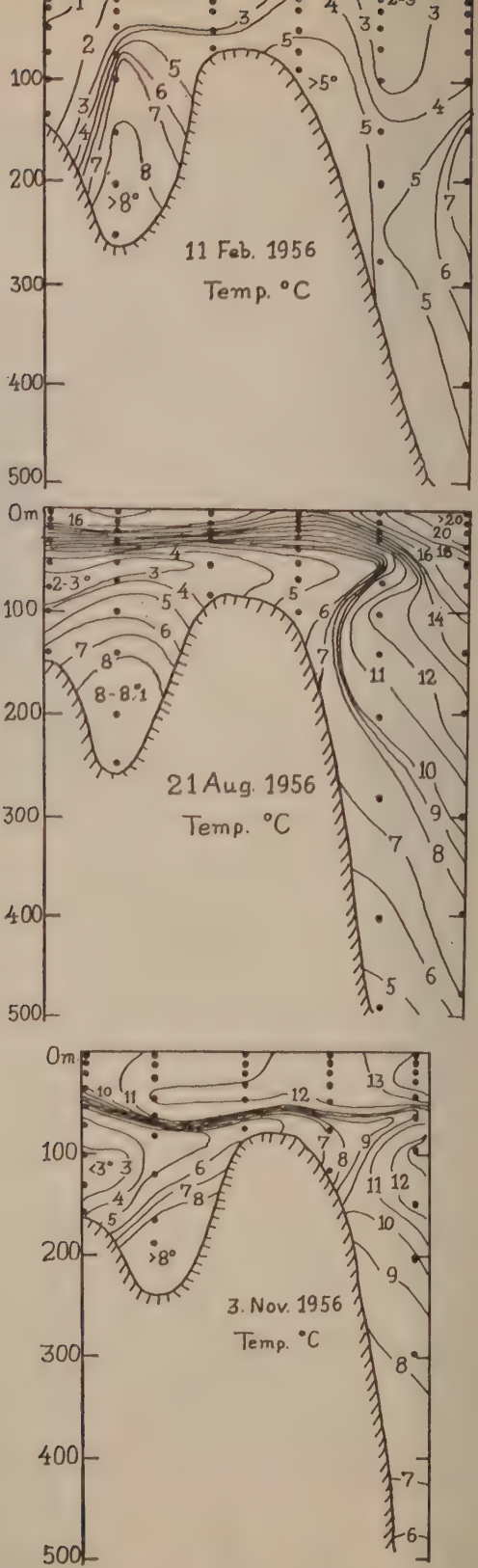
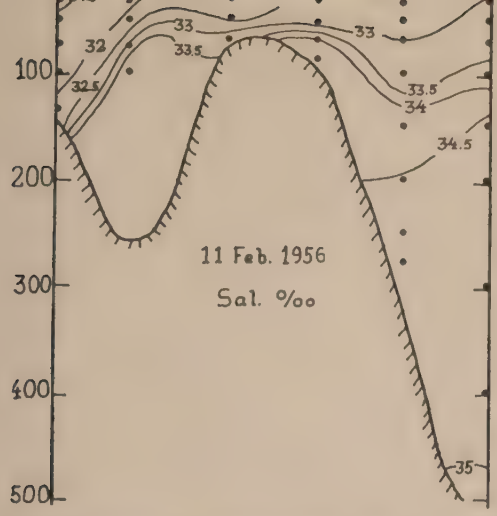


Fig. 5. Hydrographic section across the Scotian Shelf off Halifax, 1956.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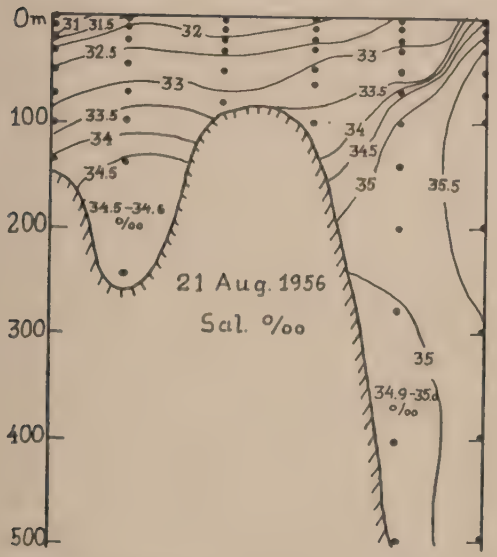
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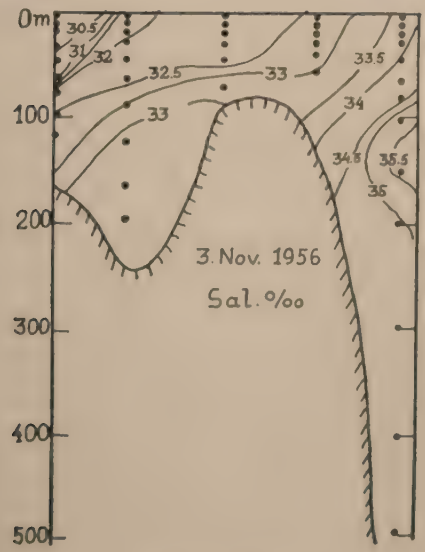
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Fig. 5. (Cont'd)

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CONTRIBUTION FROM THE FISHERIES RESEARCH BOARD OF CANADA, CHEMISTRY SECTION OF THE TECHNOLOGICAL STATION]

Marine Sterols. IV. 24-Dehydrocholesterol: Isolation from a Barnacle and Synthesis by the Wittig Reaction

BY U. H. M. FAGERLUND AND D. R. IDLER

RECEIVED JULY 8, 1957

A new sterol, 24-dehydrocholesterol, has been isolated from the barnacle *Balanus glandula*. It represents 34.2% of the total sterols of the barnacle. The major component (59.8%) is cholesterol. The new sterol also has been synthesized *via* the Wittig reaction and the synthetic product shown to be identical with the natural one. A previously reported sterol obtained by the dehydrohalogenation of 25-bromocholesterol and assigned the structure 25-dehydrocholesterol has been shown to be a mixture of 40% 25-dehydrocholesterol and 60% 24-dehydrocholesterol.

A previous investigation of the sterols of molluscs resulted in the identification of 24-methylenecholesterol as a major sterol component of several species of molluscs.[1,2] Its subsequent synthesis *via* the Wittig reaction has been reported.[3,4] Our study of the sterols of marine invertebrates has now been extended to a crustacean, the barnacle *Balanus glandula*. To the best of our knowledge cholesterol is the only sterol which has been isolated and characterized from crustaceans.[5-10] The infrared spectra of crude barnacle sterols demonstrated the absence of any significant quantity of 24-methylenecholesterol. Chromatography of the azoyl esters[11] of the crude sterol mixture resulted in three zones. The sterol of the fastest moving zone was identified as cholesterol and represents

(1) D. R. Idler and U. H. M. Fagerlund, THIS JOURNAL, **77**, 4142 (1955).
(2) U. H. M. Fagerlund and D. R. Idler, *J. Org. Chem.*, **21**, 372 (1956).
(3) D. R. Idler and U. H. M. Fagerlund, THIS JOURNAL, **79**, 1988 (1957).
(4) W. Bergmann and J. P. Dusza, *Ann.*, **603**, 36 (1957).
(5) C. Doree, *Biochem. J.*, **4**, 72 (1909).
(6) A. Leulier and A. Policard, *Compt. rend. soc. biol. Paris*, **103**, 82 (1930).
(7) C. A. Kind and E. M. Fasolino, *J. Org. Chem.*, **10**, 286 (1945).
(8) J. H. Chu, *J. Chinese Chem. Soc.*, **15**, 121 (1947).
(9) Y. Toyama and F. Shibano, *J. Chem. Soc. Japan*, **64**, 322 (1943).
(10) F. C. Vilbrandt and R. F. Abernethy, THIS JOURNAL, **53**, 2796 (1931).
(11) D. R. Idler and C. A. Baumann, *J. Biol. Chem.*, **195**, 623 (1952).

FRB No. 498

59.8% of the total sterols. The middle zone which represents 6% of the total sterol will be the subject of a future report. The slowest moving zone (34.2%) when hydrolyzed was found to be contaminated with a small amount of $\Delta^{5,7}$-sterol which was removed with maleic anhydride. The purified sterol and its derivative had properties different from those of any known sterol. Hydrogenation of the sterol with Adams catalyst in glacial acetic acid produced cholestanol with the uptake of 2 moles of hydrogen and demonstrated that the original sterol was a readily reducible cholestadienol. The modified Liebermann–Burchard reaction[12] showed that the cholestadienol had a double bond in the 5-position and that the second double bond made no significant contribution to the reaction, thus eliminating most nuclear double bonds from consideration. Ozonolysis resulted in the isolation of acetone as its 2,4-dinitrophenylhydrazone in good (51%) yield and completed the identification of the sterol as 24-dehydrocholesterol. The synthesis of this sterol *via* the Wittig reaction from 3β-acetoxy-5-cholenaldehyde and triphenylphosphine-isopropylidene was carried out in a manner analogous to that previously reported for the synthesis of 24-methylenecholesterol and 25-dehydrocholesterol. The properties of the synthetic sterol and its derivatives were identical with those of the sterol from barnacle.

With respect to the comparative biochemistry of marine invertebrates the question of the significance of 24-dehydrocholesterol in barnacles must await a comprehensive study of the sterols of other crustaceans. However, by analogy with Mollusca the results of this report already appear of interest. In Mollusca, as we ascend the evolutionary scale, we find a high percentage of Δ^7-sterols in chiton,[13,14] large quantities of 24-methylenecholesterol in Pelecypoda[1,2] and almost entirely cholesterol in Gastropoda and Cephalopoda.[15] Descending the evolutionary scale in Crustacea we find that cholesterol is the principal if not the only sterol (other than small amounts of provitamin D) in Malacostraca (crabs, shrimps, etc.);[13] Cirripedia (barnacle) has been shown here to contain cholesterol as a major component but also 24-dehydrocholesterol in large amounts. It remains to see whether cholesterol either continues to decrease or is absent in Ostracoda, Copepoda and Branchiopoda. The day may not be too far distant when the sterols of

(12) D. R. Idler and C. A. Baumann, *ibid.*, **203**, 389 (1953).

(13) Y. Toyama and T. Tanaka, *Bull. Chem. Soc., Japan*, **26**, 497 (1953).

(14) C. A. Kind and R. A. Meigs, *J. Org. Chem.*, **20**, 1116 (1955).

(15) W. Bergmann, *J. Marine Research*, **8**, 137 (1949).

a marine invertebrate will be predictable from their position in the evolutionary scale. From the biochemical viewpoint there is already evidence that unsaturation of the cholesterol sidechain may be an important factor in cholesterol metabolism.[16–18] Further studies on lower forms of marine life may well provide a means of isolating possible intermediates. A sterol, "desmosterol," has been isolated as a minor component (2%) of the sterols of chick embryo.[18] This sterol (m.p. 121.2°) is a cholestadienol. The authors suggest that it is 24-dehydrocholesterol, though sufficient evidence to prove the identity is lacking. Now that the synthetic sterol is available it should be possible to establish the identity or non-identity of "desmosterol" and 24-dehydrocholesterol. We recently reported the synthesis of 25-dehydrocholesterol[3] and showed that it is not identical with two products prepared by dehydrohalogenation and assigned this structure.[19,20] We had available for comparison an acetate of one of the earlier preparations which showed no apparent evidence of deterioration. Part of the infrared spectrum of this compound was published by us and it showed no significant absorption at 890 cm.$^{-1}$ characteristic of a terminal methylene group. The only conclusion that could be reached at that time was that the earlier preparations were probably 24-dehydrocholesterol. However, the properties of the synthetic product reported in this paper show that this is not the case (Table I). One of the earlier investigators (Dr. Dauben) has synthesized a new batch of the sterol in question and kindly supplied us with a sample so that we might resolve the problem.[21]

TABLE I

PROPERTIES OF 24- AND 25-DEHYDROCHOLESTEROL

	24-Dehydrocholesterol *via* Wittig reaction		25-Dehydrocholesterol *via* Wittig reaction		"25-Dehydrocholesterol" *via* dehydrohalogenation	
	M.p., °C.	$[\alpha]_D$	M.p., °C.	$[\alpha]_D$	M.p., °C.	$[\alpha]_D$
Sterol	117–118	−37.9°	133	−40.7°	120.5–121.5	−40.2°
Acetate	99–100	−38.8	112	−44.4	92.5–93.5	−42.8
Benzoate	131	−14.0	126	−16.7		

The infrared spectrum of the new preparation

(16) R. B. Clayton and K. Block, *Fed. Proc.*, **14**, 194 (1955).

(17) D. S. Fredrickson, M. G. Horning and C. B. Anfinsen, *ibid.*, **13**, 212 (1954).

(18) W. M. Stokes, W. A. Fish and F. C. Hickey, *J. Biol. Chem.*, **220**, 415 (1956).

(19) A. I. Ryer, W. H. Gebert and N. M. Murrill, THIS JOURNAL, **72**, 4247 (1950).

(20) W. G. Dauben and H. L. Bradlow, *ibid.*, **72**, 4248 (1950).

(21) In a personal communication Dr. Dauben reached the conclusion that his earlier preparation must have been a mixture of 25-dehydrocholesterol and 24-dehydrocholesterol.

has a significant absorption at 890 cm.$^{-1}$. We have recorded spectra of synthetic 24-dehydrocholesterol, 25-dehydrocholesterol prepared *via* the Wittig reaction, and the new product prepared by dehydrohalogenation and found the latter to be a mixture composed of 40% 25-dehydrocholesterol and 60% 24-dehydrocholesterol. It must be concluded that both the earlier preparations were originally a similar mixture and must have undergone extensive changes on storage. However, it is also probable that the composition of such a sterol mixture would vary with the reaction conditions and the number of recrystallizations.

Experimental[22]

Preparation of Crude Sterols.—In a preliminary experiment ground-up fresh barnacles (22.5 lb.) were extracted by shaking with three batches of acetone. The first extract was heated to boiling before shaking. The mass was finally washed with ether and the combined extracts were evaporated to dryness. Moisture (38.13%) was determined on an aliquot of wet barnacles, and the oil content (0.83%) was determined on a sample of the dried material. The non-saponifiable portion (4.28 g.) was chromatographed on a silicic acid:Celite column, 7.5 cm. × 10 cm., and the sterols (1.77 g.) eluted with methylene chloride after washing the chromatogram thoroughly with Skellysolve C and Skellysolve C–benzene 1:1. To obtain larger quantities of sterol, 233 lb. of fresh barnacles were extracted 3 times with hot acetone in a pilot plant. The oil (300 g.) gave 93 g. of non-saponifiables and 12.6 g. of crude sterols when chromatographed as described.

Chromatography.—The azoyl esters of the crude sterol mixture were chromatographed on silicic acid:Celite, using 5.5:1 Skellysolve C–benzene developer as previously described.[1] Three zones developed, all well separated from each other. Starting with the uppermost zone the composition was: zone 1, 34.2%; zone 2, 6.0%; and zone 3, 59.8%.

Zone 1 Acetate.—The azoyl ester was crystallized from benzene–ethanol and hydrolyzed. Calculated from the ultraviolet spectrum the sterol contained 0.85% of provitamin D. The acetate was treated with maleic anhydride in the usual manner[23] to remove provitamin D. The residue from the maleic anhydride treatment was acetylated, and the acetate, crystallized from aq. ethanol, had m.p. 101.5°, $[\alpha]^{24}D$ −39.2° (*c* 2.5 in $CHCl_3$).

Anal. Calcd. for $C_{29}H_{46}O_2$: C, 81.63; H, 10.87. Found: C, 81.59; H, 10.75.

The sterol was crystallized from aq. methanol, m.p. 117°, $[\alpha]^{22}D$ −38.7° (*c* 2.6 in $CHCl_3$). *Anal.* Calcd. for $C_{27}H_{44}O$: C, 84.31; H, 11.53. Found: C, 84.35; H, 11.44.

The benzoate was crystallized from acetone, m.p. 129°, $[\alpha]^{22}D$ −15.4° (*c* 3.1 in $CHCl_3$). *Anal.* Calcd. for $C_{34}H_{48}O_2$: C, 83.55; H, 9.90. Found: C, 83.86; H, 9.58.

Molecular rotational differences: 24-Dehydrocholesterol, Δ^{Ac} −18; Δ^{Bz} +74; Δ^5-sterols, Δ^{Ac} −35 ± 16; Δ^{Bz} +81 ± 16.

Reduction of Zone 1 Acetate.—The acetate (16.3 mg.)

(22) Melting points are uncorrected. Optical rotations were measured by means of a Rudolph precision polarimeter. Infrared spectra were recorded with a Beckman IR 4 instrument.

(23) D. R. Idler, S. W. Nicksic, D. R. Johnson, V. W. Meloche, H. A. Schuette and C. A. Baumann, This Journal, **75**, 1712 (1953).

was reduced in glacial acetic acid with platinum oxide catalyst. The hydrogen uptake was 1.78 ml. The theoretical amount for two double bonds is 1.71 ml. The reduced acetate was crystallized from aq. methanol, m.p. 111°, $[\alpha]^{22}D$ +13.6° (*c* 3.4 in $CHCl_3$), no m.p. depression with cholestanyl acetate, m.p. 111°.

Anal. Calcd. for $C_{29}H_{50}O_2$: C, 80.87; H, 11.70. Found: C, 80.91; H, 11.79.

The sterol was crystallized from aq. methanol, m.p. 141°, $[\alpha]^{22}D$ +23.6° (*c* 2.7 in $CHCl_3$), no m.p. depression with cholestanol, m.p. 142°. *Anal.* Calcd. for $C_{27}H_{48}O$: C, 83.43; H, 12.45. Found: C, 83.35; H, 12.57.

Ozonolysis.—Zone 1 sterol (530 mg.) was suspended in 10 ml. of acetone-free acetic anhydride–acetic acid (4:1) and cooled in an ice-bath. Ozone was passed through the solution until all of the solid had disappeared. Water and zinc dust were then added and the mixture was heated in a water-bath in order to decompose the ozonide. The volatile fraction was steam distilled into a water trap and the contents of this trap in turn steam distilled into a 2,4-dinitrophenylhydrazine solution. A 2,4-dinitrophenylhydrazone precipitated immediately. The crude product (175 mg.) was recrystallized twice from aqueous ethanol and melted at 128°, mixed m.p. 128° with the 2,4-dinitrophenylhydrazone of acetone (m.p. 128°).

Anal. Calcd. for $C_9H_{10}N_4O_4$: C, 45.38; H, 4.23. Found: C, 45.34; H. 4.38.

The 2,4-dinitrophenylhydrazone derivatives of the ozonolysis product and of that of acetone were chromatographed in isopropyl alcohol–water (1:1) on Whatman No. 1 filter paper treated with 5% olive oil in chloroform. The descending chromatograms were run for 2.5 days.[24] The derivatives were also run both ascending and descending in methanol–isoöctane (1:1) on untreated paper.[25] The two 2,4-dinitrophenylhydrazones had identical R_f values differing from those of formaldehyde, acetaldehyde and isobutyraldehyde.

Isopropyltriphenylphosphonium Bromide.—A pressure bottle was charged with 3.1 g. of isopropyl bromide and 6.6 g. of triphenylphosphine and was heated at 150° for one day. The crystalline precipitate weighed 6 g. It was recrystallized from a small amount of ethanol with ether, m.p. 238–239°.

Triphenylphosphine Isopropylidine Reagent.—The reagent was prepared from 3.08 g. (8 mmoles) of isopropyltriphenylphosphonium bromide, 12.9 ml. (8 mmoles) of an 0.62 *N* butyllithium solution and 25 ml. of anhydrous ether by shaking overnight at room temperature in a pressure bottle under nitrogen.

3β-Acetoxy-5-cholenaldehyde.—Ethyl 3β-acetoxy-thiol-5-cholenate was prepared according to the method of Levin, *et al.*[26] The acid chloride of 4 g. of 3β-acetoxy-5-cholenic acid was prepared and treated with ethyl mercaptan in pyridine, giving 3 g. of thiol ester, m.p. 98–101°. The thiol ester was reduced[27] with deactivated Raney nickel (30 g. of nickel alloy activated in the usual manner and partially deactivated with acetone) to give a crude product melting at 132–140°. After purification over the bisulfite addition product, 1.36 g. of aldehyde was obtained, m.p. 140–142°.

(24) R. B. Seligman and M. D. Edmonds, *Chemistry & Industry*, 1406 (1955).

(25) D. A. Buyske, L. H. Owen, P. Wilder, Jr., and M. E. Hobbs, *Anal. Chem.*, **28**, 910 (1956).

(26) R. H. Levin, A. V. McIntosh, Jr., G. B. Spero, D. E. Rayman and E. M. Meinzer, THIS JOURNAL, **70**, 511 (1948).

(27) A. V. McIntosh, Jr., E. M. Meinzer and R. H. Levin, *ibid.* **70**, 2955 (1948).

Synthesis of 24-Dehydrocholesterol Acetate.—To the alkylidene reagent in the pressure bottle was added under nitrogen 840 mg. of 3β-acetoxy-5-cholenaldehyde, m.p. 140–142°. The bottle was sealed and shaken at room temperature for one hour. It then was heated at 65° for 6 hours. The reaction product was filtered and the solid material washed several times with moist ether. The ether extracts were evaporated and the residue was acetylated and chromatographed on a silicic acid:Celite column (7.5 cm. × 14 cm.). By-products from the reaction were eluted with Skellysolve C–benzene (1:1). Benzene then eluted 205 mg. of crude 24-dehydrocholesterol acetate. The acetate was recrystallized several times from aq. ethanol, m.p. 99–100°, $[\alpha]^{23}D$ −38.8° (*c* 2.6 in $CHCl_3$), mixed m.p. 100° with the natural product.

The sterol was crystallized from aq. methanol, m.p. 117–118°, $[\alpha]^{22}D$ −37.9° (*c* 2.1 in $CHCl_3$), mixed m.p. 117° with the natural product.

The benzoate was crystallized from aq. acetone, m.p. 131°, $[\alpha]^{22}D$ −14.0° (*c* 2.7 in $CHCl_3$), mixed m.p. 130° with the natural product.

Zone 3 Sterol.—The azoyl ester was crystallized from benzene–ethanol and hydrolyzed to the sterol which was crystallized twice from aq. methanol, m.p. 148°, $[\alpha]^{22}D$ −40.2° (*c* 3.0 in $CHCl_3$), mixed m.p. 148° with cholesterol.

Anal. Calcd. for $C_{27}H_{46}O$: C, 83.87; H, 11.99. Found: C, 83.82; H, 11.92.

The acetate crystallized from aq. ethanol, m.p. 116°, $[\alpha]^{22}D$ −47.0° (*c* 3.2 in $CHCl_3$), mixed m.p. 116° with cholesteryl acetate. *Anal.* Calcd. for $C_{29}H_{48}O_2$: C, 81.25; H, 11.29. Found: C, 81.34; H, 11.23.

The benzoate was crystallized from acetone, m.p. 145°, $[\alpha]^{22}D$ −14.2° (*c* 3.1 in $CHCl_3$), mixed m.p. 145° with cholesteryl benzoate.

The infrared spectrum and the modified Liebermann–Burchard reaction were identical to those of authentic cholesterol.

Acknowledgment.—We are indebted to CIBA Pharmaceutical Products, Inc., Summit, N. J., for a sample of methyl 3β-hydroxy-5-cholenate, and to the Upjohn Co., Kalamazoo, Mich., for a sample of ethyl 3β-hydroxy-5-thiolcholenate. Mr. A. P. Ronald of our Instrumentation section recorded the infrared spectra and obtained many of the analytical data.

Vancouver 2, B. C., Canada

CHEMICAL PRESERVATION OF FOODS

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Though chemicals have been used for many decades in preservation f human foods, it is only in comparatively recent years that real progress as been made in this field. There are many references which could be quoted n this connection, but perusal of most of these indicates that relatively ew substances have been permitted by authorities whose lot it is to compile ood regulations. In a fairly recent review of the subject, Fellers (1) has isted the substances which are commonly employed in food preservation. anadian Food and Drug Regulations (2) have listed (Division 16) permitted reservatives under four classes, as follows:

1. Salt, sugar, glucose, nitrates, wood smoke, vinegar, spices, nd alcohol, and not more than 200 parts per million of sodium nitrite in cured meats and fresh fish only".

2. Benzoic acid, sulphurous acid, and sorbic acid and their salts.

3. Propionic acid and its salts, sodium diacetate and sorbic acid.

4. Antioxidants: gum guaiacum, vegetable oil containing alpha ocopherols, lecithin, citric acid, tartaric acid, ascorbic acid, propyl allate, butylated hydroxyanisole, ascorbyl palmitate, nordihydroguaiaretic cid, and isopropyl citrate.

I believe the above permitted list is very similar to that obtained n the United States. Naturally, permissions are varied with different foods; us sulphurous acid is permitted in certain types of fruit beverages but not n meats. These regulations are being improved and extended constantly, but ly after wise and very careful consideration by our Food and Drugs Division. feel that our regulatory authorities take a very sensible and scientific titude in matters concerning food additives. It is, indeed, safer for us n most instances to consume a food which is properly preserved, than to con- ume one which has undergone extensive spoilage due to growth of undesirable cteria, insect infestation, or fat oxidation. I do not think that there is y doubt that we suffer as much or more from ill-balanced diets as from in- stion of the rather few permissible chemical additives. Even relatively vilized peoples suffer from avitaminoses, and lack of minerals such as

Reprinted from, "Proceedings of the Symposium on the Future of Food reservation, Midwest Research Institute, Kansas City, Missouri, April 2-3, 957.

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calcium. We may be consuming rations too rich in cholesterol and polymerize fats and perhaps not rich enough in essential or other unsaturated fatty aci The importance of a proper calcium:phosphorus ratio has long been known, sin high levels of the one inhibit absorption of the other. Young children need fluorine to retard development of dental caries, but an excess will result i tooth enamel mottling and even in bone deformities. There are many other instances where lack, or improper balance, of nutrients will result in adver nutritional or other defects in humans, and we have much more to learn in th general aspects of nutrition.

Preservation By Antibiotics

There is not time to attempt to cover in detail the work which has been carried out on many food additives already in use, so I shall review on certain phases of the subject. Since the subject of preservation of foods b antibiotics is one of current interest it would seem reasonable that it be given rather detailed consideration.

It is rather doubtful whether it is wise to distinguish spoilage control by chemicals of the above class from that occasioned by other chemic substances. Indeed, there is really no hard and fast dividing line between the first group and other chemicals. Thus, the inorganic chemical sodium nitrite which has been used widely in Canada for fish preservation (2) is qu frequently found as a product of microbial metabolism and might be called an "antibiotic". Moreover, some antibiotics have been chemically synthesized, and it is very probable that the total synthesis of others will be achieved, especially if this can be done economically. A chemically synthesized sub- stance of this sort cannot be distinguished from the corresponding micro- biologically formed "antibiotic".

There is perhaps more danger from the psychological standpoint in the above arbitrary distinctions, for the term antibiotic has become loosely associated with medical usage, and as such has been automatically linked wit hypersensitive reactions, with development of resistance on the part of in- dividuals so that they can no longer rely on antibiotic therapy, or with re- sistance on the part of parasitic organisms so that development in their host is no longer delayed or prevented by an antibiotic. Unfortunately these dang real or imaginary, are the subject of much confused thought, not only by layn but by people whose training and position should enable them to evaluate each situation on its own merits. This subject is indeed one in which a case must be made for each individual antibiotic, or chemical. Thus one antibiotic may be in some way toxic when introduced parenterally but not when taken orally; another may be nontoxic in most respects but may be one to which consumers ma

eadily become sensitized with possible development of undesirable hyper-
ensitive reactions; still others may be useful in medicine and at the same
ime be valuable as food preservatives. I will endeavor to tell you of some
f the current uses and potential uses of antibiotic chemicals in preserva-
ion of foods intended for human consumption. Several useful reviews of
his subject are available (3, 4, 5, 6).

Probably the first attempt to use a chemical produced by a micro-
rganism to retard bacterial spoilage of a food was made about 1943 when
istrick's penicillic acid was prepared in our laboratory and tested as a
ossible preservative for fish(7). A little later penicillin and strepto-
ycin were investigated for the same purpose (8). None of these antibiotics
'fered promise for the intended purpose. About this time Curran and Evans
nvestigated the possibility that penicillin and streptomycin might prove
' value as preservative agents for milk, with disappointing results (9).
.nce these initial investigations there has been an ever-increasing expan-
.on of research concerning preservation of a variety of foods with anti-
iotics. This has continued in spite of grim prognostications and dire
rnings on the part of overly cautious and nonprogressive individuals that
ere could be no future for applications in this area. Probably these same
dividuals would have scoffed and ridiculed the early experiments which led
entually to the very valuable procedure of using antibiotics to stimulate
owth of young animals (10). My feeling is that no possibility should go
heeded in research and that it is well to remember the old adage "nothing
ntured, nothing gained".

Food preservation by use of antibiotics is no simple subject, for
t only are a very wide variety of foods involved, but the microorganisms
ich must be controlled vary with the foods in question. The immensity of
e problems is apparent when it is realized that as widely different con-
tions could be involved as are represented by control of bacteria in alco-
lic fermentations, of yeasts and molds in meat and in smoked fish, or organ-
ms which cause "rot" in chilled packaged vegetables and fruits, and of the
ychrophilic, mesophilic, and even thermophilic bacteria which cause fresh
sh and meat to spoil. Each type of spoilage represents a specific problem
l requires its own careful analysis and solution. The most spectacular
vances have been made in application of antibiotics in flesh food preserva-
on, and so these will be discussed first.

tibiotic Treatment of Meat

Though some papers dealing with antibiotic treatment of meat in
empts to retard spoilage were published in 1950 and 1951 (12, 13), it was
until the dynamic group at Ohio State University undertook research on

this subject that real progress was made. This work has appeared in a numb of scientific papers during the last few years (5, 14, 15, 16, 17, 18). It is interesting to note that these investigators came to the conclusion tha of several antibiotics studied, only aureomycin (chlortetracycline or CTC), terramycin (oxytetracycline or OTC), and chloromycetin gave promising resul and that of these aureomycin was most effective. This conclusion had been reached independently elsewhere (6, 19). Initially it was shown by the Ohi State group that, of 92 separate bacterial strains representing 12 genera a isolated from meat, 81 were sensitive to CTC, 77 to OTC and 74 to chloromyc Observations led to the conclusion that in the deep tissues of beef animals the main centers of bacterial infection were the lymph nodes. Beef rounds were pumped with 55 parts per million (ppm) of CTC in physiological saline, and when these were stored 2 days at either 3°C. or 25-30°C., it was found that the total bacterial populations of excised lymph nodes from treated animals represented only a small fraction of those obtained in nodes from u treated animals. These relatively small-scale investigations were followed by studies with whole animals infused post mortem via one carotid artery, a the results showed that the CTC treatment retarded bacterial spoilage very significantly. Surface bacterial growth on carcasses was strongly retarded by using a CTC spray. Microbiological assay results indicated that residua CTC gradually disappeared in stored meat, the rate of disappearance being m more rapid at higher temperature (e.g., 25°C.) than at lower temperatures (e.g., 3°C.). Some investigators believe there are significant possibiliti in injecting antibiotics such as CTC peritoneally into live animals one or two hours prior to slaughter. The difficulties inherent in this method, su as the relative insolubility of tetracycline antibiotics and high residual concentrations in internal organs of injected animals, has been emphasized b Deatherage (5), who does not think that this route is very practical. How- ever, some success has been achieved by other groups of investigators who h used relatively soluble tetracycline derivatives. Naturally, it is easy to apply an antibiotic treatment to ground meat products.

Treatment of Seafood

With fish, the material on which the first preservative trials wi CTC were made, the problems encountered have been rather different from tho experienced in red meat. Initial studies were small-scale trials using minc flesh and dipping procedures, and these trials indicated that CTC was the m effective antibiotic for the purpose (19, 20). Since these initial experim several investigators have contributed to our knowledge of control of fish spoilage with antibiotics. A variety of fishery products has been studied under several different conditions. It was emphasized by early investigator that, to be really effective, the antibiotic should be introduced as soon as

ossible after capture of fish. This was obviously most readily accomplished y incorporation of the antibiotic into ice used for icing fish, and in re-rigerated sea water in which they were transported, or by dipping fish in fairly strong antibiotic solution prior to icing them with ordinary ice 21). For simplicity in initial trials, CTC was incorporated in 1 to 4 ppm oncentrations in flake type of ice, and was used at 1 ppm concentration in e of this sort for icing salmon experimentally for the better part of one shing season. The results obtained indicated marked control of bacterial oilage of troll-caught salmon. Since little flake ice is produced in most shing areas the problem of obtaining block ice with uniform distribution CTC was encountered. A general solution to this problem was found in-pendently in two different laboratories (22, 23, 24, 25). Both carrageen d carboxymethylcellulose in comparatively low concentrations (e.g., 0.005 .010 per cent) were found to be effective dispersing agents for CTC. In stems lacking certain metallic salts, there was inadequate distribution CTC and it was concluded that the presence of such salts (e.g., calcium etate) is also necessary for even distribution (25). Crushed CTC-contain-g block ice, similar flake ice, and CTC-dips have given excellent protec-on against bacterial spoilage with a number of very different species of sh (6, 21, 22, 23, 25, 26, 27, 28, 29).

So far all experiments have indicated that, although CTC exerts a luable preservative effect with fish foods such as shrimp (30), crab meat 9) and oysters (31), comparatively high concentrations must be used (e.g., 20 ppm) to achieve a marked preservative effect. Presently there is no ailable explanation of this finding, but it cannot lie in the fact that all se foods have an alkaline reaction (19) because it is well known that sters possess a rather acid reaction (31, 32, 33). It is apparent that the ibiotic residue problem with these foods is very different from that ex-ienced with fish, for they may be eaten uncooked or could be antibiotic-ated subsequent to cooking.

atment of Poultry

Antibiotic treatment of poultry as a preservative measure was first olored about 1954 when the efficiency of CTC for this purpose was demon-ated (35). The fact that, in order of effectiveness, CTC, TC (tetracy-ne) and OTC (oxytetracycline) were the most useful antibiotics for this pose was also demonstrated at about this time (36). Since these original ervations were made there has been further research on this subject, and treatment of freshly killed poultry with CTC to extend the "shelf-life" eived official permission in the United States in 1955 (37). A recent ort records a study of tetracyclines and other antibiotics, and of combin-ons of CTC with antifungal antibiotics, in preservation of dressed chicken.

The results showed that under most conditions CTC was more effective than OTC and that the antifungal antibiotics suppressed yeast growth which tended to occur in CTC-treated birds. Earlier work in our laboratory had shown tha the antifungal antiobiotic rimocidin retarded yeast growth which tended to occur after rather prolonged storage in CTC-treated fish or meat samples (19 Attempts to use antibacterial effects produced by antibiotics to reduce the processing time of canned vegetables has yielded very interesting results, but as yet the general method has not reached the stage of practical applica tion. The principle involved is that of the lethal action of certain anti- biotics such as subtilin in retarding development of germinating spores, the action being enhanced by application of mild heat(39). A recent article (40 on this subject has briefly reviewed the earlier literature, and the investi gators have shown that, of some 90 antibacterial substances examined, only subtilin and nicin were really effective in reducing thermal resistance of spores of certain food-poisoning bacteria. It would seem that there are sti possibilities in intelligent applications of these or similar findings.

Treatment of Milk

It is extremely doubtful whether any preservative should be used i market milk since proper production, handling and pasteurization procedures ensure a safe product. However, in countries which are as yet backward in their food-handling procedures the tetracycline antibiotics could be used to advantage, and the tetracyclines appear to be most effective for this purpos (41, 42). Nisin-producing streptococci retard development of Clostridia in cheese (43, 44) and the antibiotic itself has been used advantageously to control gassy fermentations in this product (45). Active research is pro- ceeding in the subject of fruit and vegetable preservation with antibiotics, but so far as I am aware the results have not as yet been very promising be- cause rather high concentrations are required. However, I think that there will be advances in this area eventually.

Antibiotic Residues

The subject of antibiotic residues in treated foods has been viewe with considerable concern in some quarters. However, there is abundant evidence that CTC at least is without cumulative toxic or other undesirable effects when taken orally in small, and very often in large, concentrations (46). I think the evidence which has been presented in this connection is, in practically all respects, much more extensive than that which has been given for certain other food additives. It has, moreover, been pointed out that enormous quantities (e.g., 1 ton or more) of CTC-treated raw flesh food

ould have to be consumed before an individual would ingest a single normal ily dose of the antibiotic. With CTC, cooking of poultry causes the anti- lotic activity in the flesh to disappear (47). This has been shown to be ie to formation of harmless isomeric isochlortetracycline which is devoid of ntibiotic activity (47). With fish, the comparatively small residues which main after icing them with CTC-containing ice are largely or entirely re- oved by normal cooking procedures (28, 49). With fish CTC treatment tends repress development of Clostridium botulinum type E and of food poisoning aphylococci (28). Treatment of custard fillings with only 1 ppm of CTC or C strongly retarded development of food-poisoning organisms at 37°C. (50).

There have been other experimental uses of antibiotics in control food spoilage, but there is hardly time to mention these here. There is ttle doubt that there is a great future for experiment in this subject, and ere is every evidence that it is being attacked vigorously in a number of ading laboratories. In late September of last year, the Canadian Pure Food d Drugs Act approved the use of CTC for use in fish preservation by issuing e following statement: "No person shall sell fish that has in or upon it lortetracycline if (a) the amount thereof exceeded 5 parts per million, and) its presence is not declared by name on the main panel of the label". I derstand that there has been recent approval for use of CTC on poultry and r OTC on fish in Canada.

e Development of Food Antioxidants

One of the most interesting and indeed fruitful uses of chemicals foods has been for the purpose of protecting fats from oxidation. Oxida- e rancidity has long been recognized as a serious defect which affects vor of foods as widely different as frozen fish and various candies. In y instances it is quite practicable to retard or prevent development of dative rancidity by excluding atmospheric oxygen from the food package. wever, in many instances it has proven difficult to do this for financial other reasons, and thus the use of harmless chemical additives for this pose has become common practice. The undesirable role played by traces of vy metals, of light, heat, etc., in promoting development of oxidative ncidity is well known.

The early and prodigious work of Moureu and Dufraisse (51) which carried out about 1922 undoubtedly laid the important groundwork for the ure development of food antioxidants. They recognized the value of phenolic pounds for this purpose, and most of our presently accepted antioxidants substances of this general type. During the past decade a comparatively ge variety of compounds has been accepted for use in both the United States Canada. Thus the following may be added to fats intended for human

consumption: guaiacum resin, nordihydroguaiaretic acid (N.D.G.A.), tocophe lecithin, propyl gallate (P.G.), thiodipropionic acid and certain of its sa and esters, butylated hydroxy anisoles (B.H.A.), citric acid, ascorbic acid and its palmitate, and phosphoric acid. Some of these substances are natur present in certain foods. The function of citric and phosphoric acid, and probably of ascorbic acid, is to act as synergists, probably by binding hea metal ions.

The commercial lecithin which has been employed as an antioxidant contains a variety of substances, and it is possible that traces of tocophe are responsible for its antioxidant activity. Cephalin (52) may be respons for its synergistic activity. The antioxidant properties of the tocopherol and of gum guaiacum have been recognized for over two decades. Since the a two substances are of natural occurrence they can be used in foods. For th past 10 years there has been increasing research and development on new ant oxidants, many of which have not been compounds isolated from natural source The most important of these from the industrial standpoint are gallic acid its propyl ester, N.D.G.A., B.H.A., butylated hydroxy toluene and thiodi- propionic acid and its lauryl and stearyl esters. Though antioxidants such dimethylparaphenylenediamine and "Santoquin" offer promise for use in animal feeds should they eventually be approved for general use, there is nothing t indicate that they will be approved for use in human foods.

Though explanations of the mode of action of antioxidants have bee advanced, it cannot be stated that there is as yet complete understanding of the subject. It would seem that many of the synergistic mixtures of anti- oxidants which are sold are selected on a basis of practical effectiveness as judged by trial and error, rather than by attempted prediction from basic knowledge of the properties of the compounds involved.

The use of antioxidants has become widespread, particularly in edible fats, and their inclusion in these frequently results in a "carry ove into baked goods, cereals, etc., in the preparation of which they are used. For this reason one of the first requirements of a good antioxidant for fats has been that of heat stability.

The direct application of antioxidants to foods other than fats ha been carried out on a somewhat smaller scale, and much of the work has never reached the stage of practical application. Thus, some experiments have bee conducted with bacon, but the general opinion appears to be that a combinati of proper refrigeration and packaging, when this is coupled with the valuabl antioxidant effect of wood smoke, offers sufficient protection under normal conditions. With fish, the problem is much more acute since the fats contai a large proportion of polyunsaturated fatty acids. Some of the difficulties encountered in storage of frozen fish have recently been reviewed (57). Act research on this subject is in progress in the Food Technology Division of t

University of California (58, 59), and to some extent in our own laboratories. The position regarding use of antioxidants in fish is a little uncertain. Both ascorbic acid and isoascorbic acid have been used, and both afford marked protection against oxidation of red pigments of salmon (57) and of Atlantic rose fish (60) during storage in the frozen state. Protection of frozen fish from development of off flavors due to oxidative rancidity has been reported from some laboratories, while others have found no protection. It is possible that synergism with a naturally occurring flesh antioxidant favors the effectiveness of added ascorbic acid. A very marked synergistic effect has been observed between ascorbic acid and wood smoke in inhibiting development of oxidative rancidity in chilled salted mackerel (60).

Though early work indicated that there might be a lipoxidase enzyme in flesh materials which catalyzed formation of fatty acid hydroperoxides, this has now been disproved. All effects which have been observed can be explained on the basis of hematin catalysis (59). Partial removal of the catlyst, as by heat coagulation of myoglobin or cytochrome, hinders fat oxidation. Though adequate packaging and application of storage methods which exclude atmospheric oxidation from frozen fish are the ideal methods of counteracting rancidity development, there is still room for development of antioxidants which are more effective than those presently available (57, 59).

Color Stabilizing Agents

The use of reducing agents and other compounds in stabilizing the natural colors of foods is by no means a new departure. Ascorbic acid has long been used to retard enzymic browning of fruits intended for freezing, and this subject was adequately reviewed a few years ago (62). Sulphur oxide is widely and permittedly used to prevent Maillard reactions in dried fruits (63), as a preservative to prevent growth of bacteria and wild yeasts in wines (64) and to protect fresh fruits from microbiological spoilage (65). When enzymes are used in foods, as in the case of notatin (glucose oxidase) to remove glucose from eggs intended for dehydration (66), and proteolytic enzymes in beer clarification procedures.

One interesting, and presently permitted development, is the use of certain reducing agents to stabilize the desirable red color of cured meats. Initial research in this field (67, 68, 69) showed that inclusion of ascorbic acid in cured meats effects reduction of nitrite ions to nitric oxide, and that the latter reacts with reduced myoglobin to yield nitric oxide myoglobin. Other investigators have made significant contributions in this field (70, 71, 72), and the method has received approval for meat use in the United States (73). Reductone appears to be as effective as ascorbic acid for the above purpose (71), but dihydroxyfumaric and dihydroxymaleic acids are unsuitable (72). This is of interest in view of the comparisons which were made of

several carbonyl enediols for inhibiting development of oxidative rancidit in frozen fish (75) and of enzymic browning of fruits (74).

Another interesting problem which appears to have been at least partly solved is that of the enzymic blackening of shrimp which has been appropriately termed "melanogenesis" (76). The most effective method of re tarding this change is by storing shrimp in ice containing 0.1-0.15 per cen sodium bisulfite (77). With shrimp, ice containing CTC is not as effective retarding bacterial spoilage as it is with fish.

It has been impossible to cover all phases of the research and development which is in progress in the area of food preservation by chemic agents. I have merely attempted to give you a birds-eye view of the field. There would appear to be a great future for research on this subject for th general method is one which rarely requires extensive equipment for applica or highly skilled operators. This certainly cannot be stated for some of o present or projected techniques of food preservation.

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BRITISH COLUMBIA DEPARTMENT OF FISHERIES, 1957

The Status of the Major Herring Stocks in British Columbia in 1956-57

BY

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[REPRINTED WITHOUT CHANGE OF PAGING FROM THE REPORT OF THE BRITISH COLUMBIA DEPARTMENT OF FISHERIES, 1956]

FRB. No. 500

THE STATUS OF THE MAJOR HERRING STOCKS IN BRITISH COLUMBIA IN 1956–57

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INTRODUCTION

This report is the tenth of a series of annual reports on the results of herring research carried out at the Biological Station, Nanaimo, B.C., by the Fisheries Research Board of Canada. The various aspects of the research programme discussed in previous years were outlined in 1955–56 (Taylor, Hourston, and Outram, 1956). Continuing the policy of the past three years, the degree of integrity, present status, and level of abundance of each of the major British Columbia herring stocks in 1956–57 are discussed.

THE 1956–57 FISHERY

The total catch in the 1956–57 season (May 1st, 1956, to March 10th, 1957) amounted to 177,087 tons, the lowest since 1947–48; 30,579 tons were taken in the summer fishery lasting from the beginning of June* to the end of September, and 146,508 tons in the regular winter fishery.

The summer fishery in 1956 was more substantial and more widespread than in preceding years, with catches being made in all sub-districts except the upper west coast (Table I). In 1953, 10,600 tons were taken in the summer, 8,600 tons from the middle east coast sub-district and 2,000 tons from Swiftsure Bank (Area 21) in the lower west coast sub-district; in 1954, 4,868 tons were taken, entirely from the middle east coast sub-district; in 1955 there was no summer fishery. In 1956 the August fishery in Queen Charlotte Sound, in the upper east coast sub-district, provided 44 per cent of the total summer catch of 30,579 tons, the September fishery in Caamaño Sound in the northern sub-district 28 per cent, the lower east coast fishery (May to September) 13 per cent, and the September fishery on Swiftsure Bank 7 per cent. The remaining 8 per cent came from small fisheries in the upper and lower central, the middle east coast, and upper Queen Charlotte Islands sub-districts. In general, individual catches were small in comparison with those made in the winter fishery. Availability or catch per unit of effort (Table I) in nearly all sub-districts was much lower than in the subsequent winter fisheries.

In the regular winter fishery, catches (Table I) were below the average of the last five years in all sub-districts except the lower Queen Charlotte Islands and lower central, and, with one exception, were well below the 1955–56 catches. Only in the northern sub-district was the catch greater than in 1955–56, but still below the five-year average.

In the lower Queen Charlotte Islands, in Area 2BE, the catch was the second largest recorded, although it was only about one-third of the phenomenal catch of 85,609 tons made in 1955–56. The catch in Area 2AE of the upper Queen Charlotte Islands sub-district was sharply down in comparison to previous years and was the poorest since the area was first exploited in 1953–54. Catches were made on the west coast of the Queen Charlotte Islands for the first time in 1956–57; 117 tons were taken in one day's fishing in Renfell Sound in Area 2AW and 512 tons in Louscoone Inlet in Area 2BW during the first half of February.

In the northern sub-district, the quota was taken for the first time in three years, with the winter fishery accounting for 22,983 tons out of the season's total of 31,461

* In all sub-districts, except the lower east coast of Vancouver Island where the fishing season commences on May 1st.

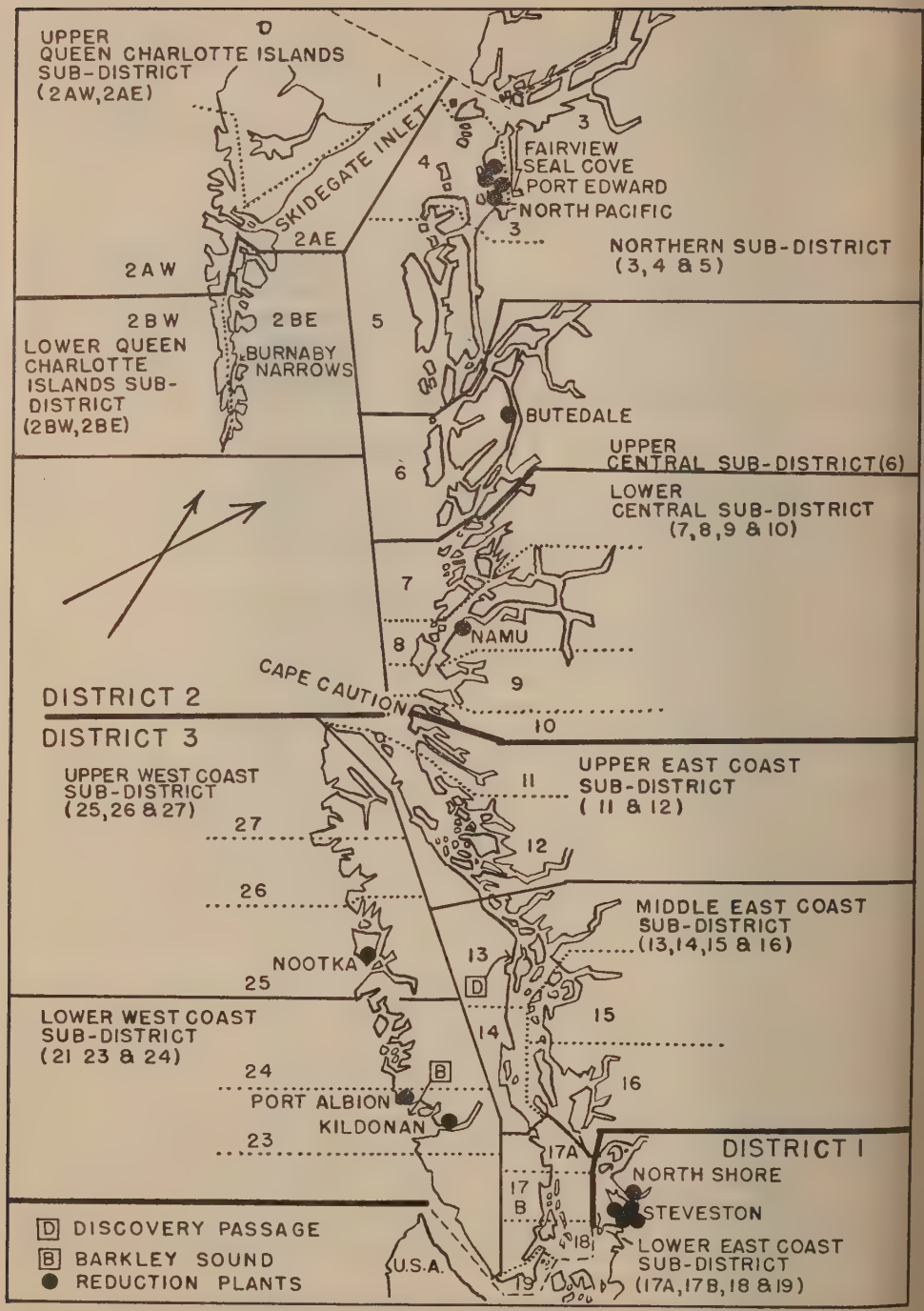

Fig. 1. Map showing the division of the British Columbia coast into districts, sub-districts, and areas.

tons. In contrast to the previous season when the fishery depended on populations (probably local) in Tuck Inlet and Morse Basin, the greater part of the 1956–57 catch was from the main migratory population fished in Hecate Strait off the southern tip of Porcher Island.

In the upper central sub-district (Area 6), the catch, although well below average, was considerably greater than in 1955–56. Meyers Pass and Green Inlet were the main fishing areas.

In the lower central sub-district (Areas 7 to 10), the catch, while slightly above the 1951–52 to 1956–57 average, was well below that of 1955–56. The main fishing-grounds were in Kilditt Sound and Kwakshua Passage, farther to the south than in the previous year.

In the middle east coast sub-district, the catch was 17,753 tons, almost double the normal quota of 10,000 tons, although only slightly more than one-half the record catch of the previous year. Almost the entire catch was made in the Deepwater Bay region of Area 13 during the first three weeks of December. In 1955–56 the main fishery occurred in January and early February, with approximately two-thirds of the catch being made in Area 13 and one-third in Area 14. Availability was higher in 1956–57 than in 1955–56.

In the lower east coast sub-district, while the quota was taken, the catch was about 20 per cent smaller than in 1955–56. Because of the delay in the start of the season due to price negotiations, this fishery, usually the first to occur, was about a month later than usual It did not start until the first week in December, and for the first time in a number of years the quota was not taken before the Christmas closure. Availability was about the same as in 1955–56.

The catch in the lower west coast sub-district was the lowest recorded. Almost the entire catch was made in Barkley Sound, and represented the smallest catch from this area since 1941–42. The upper west coast sub-district produced only 541 tons of fish, almost all from Ououkinish Inlet. In spite of the low catch, the level of abundance in this sub-district, as indicated by the amount of spawn deposited, was probably above average.

TAGGING

The coastwise adult herring tagging programme was discontinued after 1954, when it was considered that the general relationship between most major populations was sufficiently well understood for the practical purposes of management, and that the annual variations in the extent of intermingling between populations were not large enough to warrant the continued expenditure entailed (Taylor, 1955). In 1955 and 1956 adult tagging was confined to the Strait of Georgia in an effort to determine more precisely the complex relationships between the middle and lower east coast populations. This programme was suspended after the 1956 season when it became apparent that no additional information was likely to be obtained because of difficulties in separating tags recovered from these populations when the fisheries occur, as is often the case, at approximately the same time. No adult herring were tagged, therefore, in the spring of 1957.

Juvenile herring also have been tagged to provide information on the juvenile stocks reared in certain areas and on the spawning stocks that support the fisheries in these and other areas (Taylor, Hourston, and Outram, 1956). From 1952 to 1954 this programme was confined to the lower west coast sub-district and in 1955 and 1956 to populations in the Strait of Georgia and adjacent San Juan Islands area. This programme was terminated after the 1956 season, when the entire juvenile herring research programme was discontinued. The data on the 1956 juvenile herring taggings are summarized below:—

Sub-district and Area of Tagging	Number Tagged in 1956
Middle East Coast—	
Area 13	3,130
Area 14	4,060
Area 15	7,253
Area 16	3,102
Lower East Coast—	
Area 17A	3,075
Area 17B	3,023
Area 18	6,058
Area 19	3,106
San Juan Islands	6,003
Total	38,810

TAG RECOVERY

In the 1956–57 season, tags were recovered only by magnets in reduction-plant meal-lines. No tag-detector was operated, even on an experimental basis, because the difficulties introduced by the increased use of electricity to operate plant machinery proved insurmountable (Taylor *et al.*, 1956).

For reasons discussed in previous reports (*see* Taylor *et al.*, 1956), the various reduction plants differ in their efficiency in recovering and submitting tags found on the magnets. Tests to determine the efficiency of the various plants in recovering tags were conducted in the same manner as in previous years (Stevenson, Hourston, Jackson, and Outram, 1952). The average efficiency of each plant in 1956–57, together with its average efficiency in 1955–56 in parentheses, is given below:—

Plant	Adult Tags		Juvenile Tags	
	Number of Tests	Average Efficiency	Number of Tests	Average Efficiency
West Coast of Vancouver Island				
Port Albion	1 (1)	92 (92)	1 (1)	60 (60)
Steveston and Vicinity				
Imperial	1 (3)	84 (84)	1 (3)	60 (53)
Gulf of Georgia	1 (3)	98 (94)	1 (3)	70 (80)
Colonial	1 (2)	68 (76)	1 (2)	30 (60)
Phoenix	1 (3)	96 (97)	1 (3)	70 (85)
North Shore	1 (2)	86 (89)	1 (2)	90 (75)
Average		87 (88)		64 (71)
North and Central British Columbia				
Namu	1 (2)	96 (91)	1 (2)	70 (65)
Butedale	(1)	92 (92)	(1)	(70)
Port Edward	2 (2)	68 (78)	2 (2)	55 (50)
Seal Cove	1 (2)	64 (79)	(2)	(35)
Fairview	2 (2)	90 (71)	2 (2)	80 (60)
North Pacific	1 (2)	90 (81)	1 (2)	30 (70)
Average		82 (82)		59 (58)

In 1956–57 there was little change in the general level of efficiency of adult tag recovery. Fairview and North Pacific plants in the Prince Rupert area showed increases in efficiency, while Colonial and Port Edward showed substantial decreases for the second year in succession. The Seal Cove plant has always been relatively inefficient in recovering tags. After an increase in 1955–56, the efficiency of this plant in 1956–57 fell to its normal level.

The average efficiency of the major plants in Northern British Columbia in recovering juvenile herring tags was about the same as in 1955–56, while the efficiency of plants in

Southern British Columbia was somewhat less. Again, there was considerable variation in efficiency among individual plants. The greatest changes were at Colonial and North Pacific, where sharp decreases occurred, and at North Shore and Fairview, where marked increases in efficiency were recorded. Over the past four seasons there has been a decrease in the relative efficiency of juvenile tag recovery. In 1956–57 the ratio of juvenile to adult efficiency was 0.74; in 1955–56, 0.77; in 1954–55, 0.78; and in 1953–54, 0.83.

A total of 1,708 tags, including nineteen State of Washington tags, were recovered in 1956–57 from the magnets in twelve reduction plants. Of these, 272 were recovered in the summer and early fall fishery, the remainder in the regular winter fishery.

Using the same methods as in previous years (Tester and Stevenson, 1948), the most probable area of recovery has been determined for each plant magnet return (Table II). The tendency for reduction plants to process fish simultaneously from a number of different areas was accentuated in 1956–57 by the delay in the start of the regular winter fishery. As a result, only a small proportion, 516 out of 1,436, or 36 per cent, of the tags recovered could be assigned with any certainty to a particular area of recovery. Recoveries from the middle and lower east coast sub-districts were the most seriously affected. Of 1,152 fish tagged and possibly recovered in these two sub-districts, the most probable area of recovery could be determined for only 239 or 21 per cent.

To assess movement between populations, the probable numbers of tags in the catches were calculated from the plant magnet returns (Table III). The method used was described by Taylor and Outram (1954). Tags recovered at Port Albion and Butedale reduction plants were omitted, as no magnet efficiency tests were carried out at these two plants. Because of the relatively small numbers of tags certain as to area of recovery (Table III, column 9), the estimates of movement between populations are considered generally less reliable in 1956–57 than in previous years. Certain other sources of error are also liable to affect these estimates:—

(1) The length of time the tagged fish have been at liberty. In 1955 and 1956 only the middle and lower east coast populations were tagged. The remaining populations have not been tagged since 1954. The majority of the recoveries from the middle and lower east coast populations in 1956–57, as in previous years, were mainly from fish that had been at liberty for one or two seasons.* From all other populations, recoveries were from fish that had been at liberty for three or more seasons. Because of the greater time at liberty, estimates of movement based on these recoveries may not be strictly comparable to estimates in previous years or to estimates for the middle and lower east coast populations. On the basis of recoveries in 1955–56, the tendency for the degree of dispersion from the sub-district of tagging to increase the longer the fish had been at liberty was not sufficiently marked to warrant the assessment of movement on the basis of recoveries from fish at liberty for the same number of years (Taylor, Hourston, and Outram, 1956). In 1956–57, because of the additional year of liberty, this tendency might be expected to be more pronounced. However, the number of recoveries certain as to area of recovery was insufficient to provide a reliable test of this possibility.

(2) Differences in the degree of exploitation of the various populations both in the same season and in different seasons. As the number of tags recovered varies with the size of the catch, differences in the amount of fish caught in the area of tagging and in areas receiving tags from it will affect estimates of the amount of movement between areas. Similarly, if the proportional sizes of the catches vary from year to year, comparisons of

* More exactly eight or twenty months, since herring are tagged in March and the fishery develops in November.

the degree of dispersion between years will also be affected. Errors of this type might be minimized if estimates of dispersion were based on calculations of the probable number of tags per ton in the various areas. However, because of the large and variable number of tags doubtful as to area of recovery, such calculations would not be reliable.

Since the catches in the lower Queen Charlotte Islands and northern sub-districts have varied widely in the last three seasons and since neither population has been tagged since 1954, estimates of the migration of fish from these two populations will be affected the most seriously by errors from the above two sources. Estimates of dispersion from the middle and lower east coast populations will be the least affected, since catches in each have varied little in the past three years and since both have been tagged every year.

Because of the relatively small number of tag returns certain as to area of recovery and because of the possibility of additional errors from the sources discussed above, estimates of movements between populations in 1956–57 should be accepted with caution.

(1) In 1956–57 most of the recoveries from the regular winter fishery were from the sub-district of tagging and confirm previous conclusions on the relative discreteness of the major populations. The "homing" tendency was apparently least pronounced in the upper Queen Charlotte Islands population (Area 2AE) and most pronounced in the lower east coast population.

(2) The apparent emigration of 44 per cent (14/32) from Area 2AE to the northern sub-district was very much greater in 1956–57 than in previous seasons. This estimate may be unreliable because of the small number of tags involved. It may reflect in part a greater degree of dispersion related to the longer period the tagged fish were at liberty, but more probably overestimates the true movement because of the great difference in the sizes of the catches in the two regions (Table I).

(3) Emigration from the lower Queen Charlotte Islands population (Area 2BE) amounted to 22 per cent (21/94) in 1956–57, compared to 3 per cent in 1955–56. The majority of the emigrants (17) were recovered in the northern sub-district, and the remainder in the lower central sub-district. Once again the apparent increase in emigration may be due to increased time at liberty, but more probably it is a reflection of the smaller relative difference in the sizes of the catches in the two regions (Table I). Eighty per cent (73/91) of the recoveries from the lower Queen Charlotte Islands region were from fish tagged there, 8 per cent (7/91) were from the northern sub-district, and 10 per cent (9/91) from the upper and lower central sub-districts.

(4) Of the recoveries of fish tagged in the northern sub-district, 8 per cent (7/97) were from the lower Queen Charlotte Islands area and 13 per cent (13/97) from the lower central sub-district. Emigration in 1956–57 was similar to the average emigration (23 per cent) between 1936 and 1952 (Stevenson, 1955) and very much less than the estimate in 1955–56. The apparently great emigration in 1955–56 may have been the result of the dependence of the fishery on the isolated untagged stocks of herring in Tuck Inlet and Morse Basin rather than on the main migratory northern sub-district population tagged in previous years (Taylor, Hourston, and Outram, 1956). Thus the number of returns from the northern sub-district from fish tagged there would be proportionately smaller than normal in comparison with the number of returns from other regions. In 1956–57 the fishery, although centred farther to seaward than in other years, again apparently depended on the main migratory northern popu-

lation. Sixty-eight per cent (76/112) of the recoveries made in the northern sub-district were of fish tagged there, 15 per cent (17/112) were from the lower Queen Charlotte Islands, and 12 per cent (14/112) from the upper Queen Charlotte Islands. The remaining 5 per cent were from the upper and lower central sub-districts.

(5) Emigration from the lower central sub-district amounted to 8 per cent (13/150) in 1956–57, with the major portion (5 per cent) again to the lower Queen Charlotte Islands sub-district. Limited movement occurred to the northern and middle east coast sub-districts. The pattern of emigration from the lower central sub-district was similar to that in previous years, in spite of the fact that the main centre of the fishery shifted southwards from the Thompson Channel-Seaforth Channel region to the Kilditt Sound-Kwakshua Passage region. Of the recoveries made in the lower central sub-district, 80 per cent (138/172) were from fish tagged there, 6 per cent from fish tagged in the upper central sub-district, 7 per cent from fish tagged in the northern sub-district, 4 per cent from the middle east coast, and 2 per cent from the lower Queen Charlotte Islands sub-district.

(6) The fishery in the upper central sub-district was again too small to be able to assign tag recoveries to it with any degree of certainty. About 77 per cent (10/13) of the recoveries from fish tagged in this sub-district were apparently recovered in the lower central sub-district. The remainder were recovered from the northern and lower Queen Charlotte Islands sub-districts.

(7) Movement from the middle east coast population amounted to 28 per cent (58/204) in 1956–57, considerably greater than in the previous two seasons (6 per cent in 1955–56 and 4 per cent in 1954–55) but less than the average of 45 per cent for the years 1936 to 1952 (Stevenson, 1955). The majority of the emigation (25 per cent) was to the lower east coast, as compared to 5 per cent in 1955–56 and 2 per cent in 1954–55. Emigration to the lower east coast was greatest from Area 14 and least from Area 13. Of recoveries made in the middle east coast sub-district, 97 per cent (146/150) were from fish tagged there, the remaining 3 per cent coming from the northern, lower central, and lower east coast populations.

(8) The apparent dispersion of lower east coast herring to other sub-districts (3 per cent) was less in 1956–57 than in 1955–56 (about 15 per cent). It was all to the middle east coast sub-district. Only 54 per cent (59/110) of the recoveries from the lower east coast sub-district were from fish tagged there, and 46 per cent were from the middle east coast. The remainder were fish tagged in the San Juan Islands.

(9) No tags certain as to area of recovery were obtained from the small west coast fishery.

In 1956–57 there was a substantial summer and early fall fishery with a total catch of 30,579 tons (Table I). Tags were recovered from the summer fisheries in the northern, upper east coast, middle east coast, lower east coast, and lower west coast sub-districts.

Of the eight tags from the northern sub-district landings, six were from fish tagged in that sub-district and the remaining two from fish tagged in the lower central sub-district.

The probable number of tags in the relatively large upper east coast fishery was seventeen—fifteen from fish tagged in the middle east coast sub-district and two from fish tagged in the lower central sub-district. The relatively small number of recoveries suggests that while the stocks contained some middle east coast and a few lower central

sub-district fish, the majority most probably were from the upper east coast population, which has only been very lightly tagged in the past five years, rather than from some previously unexploited stock.

The relatively small middle east coast summer fishery yielded sixty-two tags certain as to area of recovery. Of these, 74 per cent (46/62) were from the middle east coast sub-district, mainly from Area 14, and 25 per cent (15/62) from the lower east coast sub-district. Recoveries from the summer fishery in 1953–54 showed a similar distribution, with 73 per cent of the recoveries from taggings in the middle east coast sub-district and 22 per cent from the lower east coast sub-district. In the winter fisheries in the same two seasons in this sub-district, 88 and 97 per cent respectively of the recoveries were from middle east coast tagged fish and 8 and 2 per cent respectively from lower east coast tagged fish. In both the summer and winter fisheries in 1954–55, the percentages of middle east coast tagged fish were lower (47 and 60 per cent respectively) and the percentages of lower east coast tagged fish higher (44 and 15 per cent respectively). The 1954–55 results were, however, probably biased by the large number of recoveries in the summer and winter fisheries from a lower east coast tagging on the border between the two sub-districts.

In the summer of 1956 there was a substantial fishery for reduction purposes in the lower east coast sub-district for the first time. This fishery yielded 196 tags certain as to area of recovery. Of these, 57 per cent were from fish tagged in the lower east coast sub-district, and 43 per cent from fish tagged in the middle east coast sub-district, a pattern of recoveries similar to that obtained in the regular winter fishery.

A total of eleven tags were contained in the Area 21 catches—five, or 46 per cent, from fish tagged in the middle east coast sub-district and four, or 36 per cent, from the lower east coast sub-district. There was one recovery each from an American tagging in the San Juan Islands and from an upper west coast tagging. Because of the small number of recoveries and because of the lack of tagging in the lower west coast sub-district after the spring of 1954, these results cannot be considered reliable. In 1953–54 there was also a summer fishery in Area 21. In this fishery 46 per cent (17/37) of the recoveries were from fish tagged in the lower west coast sub-district, 43 per cent (16/37) from the lower east coast sub-district, and 8 per cent (3/37) from the middle east coast sub-district. In contrast, in the 1953–54 winter fishery 95 per cent of the recoveries were from lower west coast taggings, with only 1 per cent from the lower east coast.

In the middle and lower east coast sub-districts, tag recoveries suggest that, while in the summer there may be a greater degree of intermingling with adjacent populations, the stocks are the same as those fished in the winter. In Area 21 the stocks fished in summer probably consist predominantly of fish that spawn in the lower west coast and lower east coast sub-districts. Fish from the middle east coast sub-district are also present, and in some years, at least, may form an appreciable portion of the stock. The recoveries of fish from the upper east coast, lower east coast, and lower west coast fisheries which were tagged in the middle east coast sub-district tend to confirm the hypothesis that middle east coast herring migrate seaward both northward through Johnstone Strait and southward through the Strait of Juan de Fuca, but suggest that possibly the southward route in some years may be the dominant one.

However, because of the small numbers of recoveries from all summer fisheries, these conclusions on summer intermingling must be treated with caution.

RECOVERY OF JUVENILE HERRING TAGS

Three juvenile herring tags were recovered in 1956–57. Two were from fish tagged in Barkley Sound in 1953—one was recovered in the upper west coast sub-district, the other in either the middle or lower east coast sub-district. The third recovery, made in the lower east coast sub-district, was from fish tagged in Jervis Inlet (Area 16) in 1954.

SAMPLING

The objective of a sampling programme is to obtain a number of individuals from a population, the average and range of whose characteristics are representative of the entire population. Each fishing season, random samples of the herring-catch are taken at the reduction plants, and age, length, weight, sex, and degree of maturity are recorded for each of a standard number of fish from every sample. Practical difficulties preclude attaining a perfect representation of the fishable stocks, but examination of the sampling data from previous years has indicated two aspects of the programme in which improvement could be made within the scope of our present operations.

Firstly, the annual goal of a sample taken from every unit (that is, a certain number of tons) of fish caught seldom has been attained except at plants in the Vancouver area, where Biological Station personnel were established throughout the fishing season. Sampling at other plants is done by plant personnel who are subject to other demands on their time and who show varying degrees of conscientiousness. Since the Vancouver plants process mainly fish from the southern stocks (District 3, Fig. 1), information on the northern stocks has not been nearly so complete and reliable as that on the southern stocks. In an attempt to overcome this bias, a field station was established in Prince Rupert during the 1956–57 season to give comparable coverage on the fish landed in that area. Plants in the Prince Rupert and Vancouver areas, which handle 65 per cent of the total catch, process appreciable amounts from all sub-districts. To increase the coverage at other plants, the numbers of samples requested were increased to 50 per cent more than the number desired, and then these samples were sub-sampled to obtain a comparable catch-sample ratio.

Secondly, it has been noted in past sampling programmes that two or more samples taken from the same locality on the same day may differ appreciably in their composition. In order to increase the coverage of the catch by samples, the 1956–57 programme was set up to include double the number of samples. Because the mean and range of variation in the characters sampled are demonstrated almost equally well by the first fifty fish in a sample as by 100 fish, it was possible to double the number of samples without increasing the number of fish to be processed by reducing the size of the samples to fifty fish.

AGE COMPOSITION AND YEAR-CLASS STRENGTH

The age of a herring can be determined from the number of growth seasons shown on its scales. Age determinations were made for each of fifty fish in forty-five samples obtained from the summer fishery in 1956 and in 575 samples obtained during the 1956–57 winter fishing season. (In 1955–56, 288 samples of 100 fish were employed.) One sample was taken for every 680 tons of fish caught in the summer fishery and for every 250 tons caught in the regular winter fishery, as opposed to one sample for every 900 tons in the previous winter season. Percentage age composition was calculated from these data for the ten major British Columbia herring populations and for stocks on the west coast of the Queen Charlotte Islands in the regular winter fishery and for fish from various statistical areas by months for the summer fishery (Table IV). These data, along with data on the average weight of fish at each age in each population (Table VII) and the total catch taken from each population (Table I), give an estimate of the number of fish at each age taken by the summer and winter fisheries from each population (Table V). Data from Table IV show the relative contributions of the various year-classes to the stocks, while data from Table V show the relative importance of these year-classes in the catch from the various populations.

Data from the winter fishery indicate that the 1954 year-class dominated in most populations and appears to be somewhat stronger than the below-average 1953 year-class. A notable exception was the northern sub-district, where the 1953 year-class, of above-

average strength in that sub-district, dominated the catch. The 1955 year-class made a strong showing in the upper central and upper east coast sub-districts and may be stronger than the 1954 year-class in these populations. The strong 1951 year-class (VI-year fish) again made appreciable contributions to the lower Queen Charlotte Islands, lower central, upper east coast, and middle east coast populations, where it had dominated in the previous year's catch. However, after four successive years of supporting the fishery in most of these populations, its numbers have been reduced to a level where it can no longer be expected to make major contributions to future fisheries.* On the basis of its contributions as II-year-old fish, the 1955 year-class appears to be above average in the District 2 and upper east coast populations but below average in those farther south.

Thus the general picture of recruitment in recent years along the coast is that of a very strong 1951 year-class followed by a weak 1952 year-class, a below-average 1953 year-class, an average 1954 year-class, and finally the 1955 year-class, which appears above average in the north but weak in the south. Abundance in most populations reached a high level when the strong 1951 year-class was recruited and then declined as this year-class moved through the fishery. The 1951 year-class held abundance at a fairly high level as the poor 1952 year-class moved through the fishery, and the decline was buffered somewhat as the 1953 and 1954 year-classes made somewhat stronger, although no more than average, contributions to the stocks. The apparently good 1955 year-class may hold abundance at is present level in the north, but further declines can be anticipated in the south.

The year-class newly recruited as III-year fish continued to dominate in the lower east coast and lower and upper west coast populations, indicating no major variation in year-class strength in these regions. The middle east coast and lower central populations have reverted to this pattern with the disappearance of the 1951 year-class as an important contributor to the catch. Fish of age III (the 1954 year-class) also dominated the stocks in both areas on the west coast of the Queen Charlotte Islands, forming a somewhat larger proportion of the catch in the northerly than in the southerly area. The more usual situation in the north of extended recruitment with several year-classes dominating the catch obtained in the upper and lower east coasts of the Queen Charlotte Islands and upper central populations. These populations were made up largely of III-, IV-, and VI-year fish, II-, III-, and VI-year fish, and II- and III-year fish respectively. The poor 1952 year-class (V-year fish) in all these populations and the poor 1953 year-class (IV-year fish) in the lower east coast of the Queen Charlotte Islands and upper central populations disrupted this pattern only slightly. The 1953 year-class (IV-year fish) appears to be the only one recruited to the northern population since 1951 which was not below average, and it alone dominated the population in 1956–57.

In the summer of 1956, in the lower east coast sub-district (Areas 17A, 17B, 18, and 19) the 1953 year-class as IV-year-old fish formed the greatest proportion of the population from June to August. In September and in the regular winter fishery, the 1954 year-class (age III) was the dominant contributor. In the middle east coast sub-district in September, the 1953 year-class contributed the largest number of fish, but in the regular winter fishery the 1954 year-class did. In the upper east coast sub-district in June the 1952 year-class was the largest contributor, in July and August the 1954 year-class was, and in the regular winter fishery the 1955 year-class (age II) provided the most fish. In the upper and lower central sub-districts the 1951 year-class (age VI) was dominant in September, while in the regular winter fishery the 1954 year-class was dominant in the lower central and the 1955 year-class (age II) in the upper central.

In all areas the stocks providing the summer fisheries contained a smaller proportion of younger fish and a larger proportion of older fish than the equivalent winter populations. In areas where samples were available for several summer months, there is an indication of a relatively small but progressive increase in the proportion of younger fish

as the summer progresses. In late summer or early fall before the winter fishery commences, a sharp increase occurs in the proportion of fish in those age-groups where recruitment is greatest. Thus, in all populations, the proportion of III-year-old fish increases in this interval. The increases are less marked in the middle east coast and the northern and central British Columbia populations, where a greater proportion of the recruitment occurs at older ages and hence where fish of age III generally form a smaller proportion of the population.

The differences in age composition between summer- and winter-fished stocks suggest that the new recruits do not join the fishable stocks until the time of the autumn prespawning migration. The summer stocks appear to consist mainly of fish recruited in previous years and are the residues of the previous season's spawning populations.

AVERAGE LENGTH AND WEIGHT

In six of the ten major herring populations, upper and lower east coast of the Queen Charlotte Islands, northern, upper central, upper east coast, and lower west coast fish of each age were larger, on the average, in the winter of 1956–57, than in the previous year and than the ten-year average for the seasons 1946–47 to 1955–56 (Tables VI and VII). In some of these populations, however, the II-year fish were smaller than average or than in 1955–56. In the lower central and upper west coast sub-districts the fish were smaller than average and the lower central fish were smaller than in the previous season. (No data were obtained for the upper west coast in 1955–56.) Fish taken from the other two sub-districts (lower and middle east coast) were similar in length to the previous year and to the ten-year average. Irregularities in the average length and weight patterns of fish younger than III years and older than VI years probably reflect the relatively small numbers of fish sampled from these age-groups.

In animal populations there is often an inverse relationship between the relative size of the population and the growth rate of individuals comprising it—that is, the population limits the amount of food available to the individual. This situation appears to apply roughly in 1956–57 to all but the northern population. Abundance in 1956–57 was generally low except for the upper west coast, lower central, and northern populations, and average size was greater except in the upper west coast and lower central populations. However, catch, spawn deposition, and average size were all high in the northern subdistrict. This anomalous situation might be related to the fact than 97 per cent of the northern catch was taken on the offshore grounds fished intensively for the first time in 1956–57. If these fish were from other than the northern stock, abundance would be low in the northern population and size would consequently be greater. However, tag returns indicated that these were the northern stocks fished prior to 1955–56. The most probable explanation, therefore, appears to be that the abundance and (or) distribution of the planktonic food-supply of this population was unusually favourable in 1956 and in excess of the population requirements.

The somewhat erratic growth pattern presented by the average lengths and weights of herring from the summer fisheries may be due in part to sampling inadequacies. The number of samples from any area for any month is small and may not provide a reliable indication of the population average lengths and weights. The data (Tables VI and VII) suggest that the fish in summer are longer and heavier in all populations, except the lower central, where the summer fishery (in Area 8) may have depended on a slower-growing local population. Two possible explanations of the larger size of summer-caught herring are offered. Environmental conditions may be more suitable for growth in those localities where the summer fisheries occurred than in those where the fish caught in winter had spent the summer, or more probably, considering that the greatest differences occur among the younger fish, that the younger age-groups in the summer stocks contain a greater proportion of earlier-maturing, faster-growing fish than do the same age-groups

in the winter stocks. In the lower east coast sub-district there is also some indication of a progressive increase in average length and weight during the summer until September, when the fish appear intermediate in size between those taken earlier and winter-caught fish. The different size and age composition of fish taken in September may be the result of the first incursion of the winter stocks. In other sub-districts the trend in growth during the summer is less obvious and more erratic from age-group to age-group.

SEX RATIO

Females continued to slightly outnumber the males in the British Columbia herring stocks (Table VIII). The high sex ratios in the lower west of the Queen Charlotte Islands and the upper west coast populations probably reflect poor sampling as only two samples were obtained from each of these populations. The generally lower sex ratios in 1956–57 presumably result from the reduced number of older fish in the stocks as females tend to live longer and thus dominate the older age-groups. The only heavily sampled population (northern) which showed an increase in sex ratio over 1955–56 was also the only one to show a significant increase in average age.

EXTENT AND INTENSITY OF SPAWNING

Each year, officers of the Federal Department of Fisheries measure the extent and intensity of herring-spawn depositions along the entire British Columbia coast-line. Independent and more detailed surveys are also carried out by Biological Station personnel in certain regions. In 1955 and 1956, the lower and middle east coast sub-districts were surveyed, but in 1957, only the latter sub-district and the Boundary Bay region were searched for spawn.

Estimates of the extent and intensity of spawn depositions provide an index of the size of the relative spawning escapements, since natural mortality during the short period between the close of the fishery and the commencement of spawning can be considered negligible. A measure of the extent of spawn deposition also provides information on the initial size of the new year-class.

The length of each individual spawning-ground was measured by pacing along the beach or by reference to detailed charts. Compensation was made for width, only when this dimension was greater than 100 yards or less than 5 yards. In these cases the reported length was converted to an equivalent length at a standard width of 30 yards. The intensity on each spawning was estimated in terms of one of five categories—very light, light, medium, heavy, or very heavy—depending on the number of eggs per unit area of vegetation. The length of each spawning at the reported intensity was converted to an equivalent length in statutory miles at a standard intensity of medium, and the results totalled for each statistical area. By summing the area totals, an estimate of the amount of spawn deposited in 1957 in each sub-district and on the coast as a whole was obtained (Table IX).

A total of 131.5 miles of herring spawn at standard intensity was deposited in British Columbia coastal waters in 1957, the lowest amount ever recorded, and a reduction of 30 per cent from the 1956 level. The number of miles of spawn deposited in 1957 decreased markedly in six sub-districts, increased slightly in two sub-districts, and substantially in one.

Sub-district	Per Cent Reduction	Per Cent Increase
Upper Queen Charlotte Islands	(1)	(1)
Lower Queen Charlotte Islands	71	-----
Northern	-----	56
Upper central	-----	200[2]

[1] No change.

[2] Although the per cent increase in the upper central sub-district is very large, the actual increase in miles of spawn is small; deposition in 1957 was less than a mile for the second successive year.

Sub-district	Per Cent Reduction	Per Cent Increase
Lower central	39	-----
Upper east coast	38	-----
Middle east coast	56	-----
Lower east coast	-----	6
Lower west coast	33	-----
Upper west coast	55	-----

In the upper Queen Charlotte Islands sub-district, spawning in Area 2AE was almost negligible for the third successive year. A small spawning of 0.11 mile was located in Seal Inlet in Area 2AW. This is one of the few reports ever received from the west coast of the Queen Charlotte Islands. In the lower Queen Charlotte Islands sub-district (Area 2BE), spawning was drastically reduced. Only one spawning of any consequence (at Burnaby Narrows) was reported from this sub-district.

In the northern sub-district, the above-average spawn deposition was due primarily to a record spawning in Area 3, principally in the vicinity of Port Simpson. The extent of spawn also showed an increase in Area 4 for the second successive year. In both the upper and lower central sub-districts, the amounts of spawn found were well below average for the second successive year. The absence of any spawnings in the usually productive Myers Pass-Kitasu Bay region (Area 6) for the second year in a row were primarily responsible for the low level of spawning in the upper central sub-district. In the lower central sub-district, a small increase in spawn deposition in Area 8 was more than offset by substantial reduction in Area 7. The lack of spawning along the north and south-west coast of Campbell Island (Area 7) caused the reduction in the lower central sub-district.

In the upper east coast sub-district, spawning was well below the average for the last twenty years. Although spawn deposition occurred on all the usual spawning-grounds, the individual spawnings were reduced in size and intensity from 1956. A small spawning occurred at Nugent Sound (Area 11) for the first time since 1954.

In the middle east coast sub-district, the extent of spawn was less than one-half of the previous year. Marked reduction in the number of spawnings in Area 14, particularly in the Comox Harbour vicinity, were primarily responsible for the decrease. While no spawn was observed in Area 15 in 1956, 3.2 miles were found there in 1957.

In the lower east coast sub-district, spawn deposition increased slightly in 1957. Exceptionally heavy and extensive spawnings in Nanoose Bay in Area 17A more than offset the very reduced spawnings in Area 17B, where, following four years of progressive reduction, spawning in 1957 for the first time on record was negligible.

In the lower west coast sub-district, spawning was below average. The absence of the usual spawnings in Useless Inlet (Area 23) was mainly responsible for the reduced 1957 level of spawn deposition in this sub-district. The reduction in deposition in Area 23 was partly compensated for by a small increase in the extent of deposition in Area 24.

In the upper west coast sub-district, spawn deposition in 1957, while less than one-half of that of the previous year, was still about average. The decrease in spawn deposition in 1957 was due primarily to a reduction in the size of the usually large spawning at Nuchatlitz (Area 25). In 1956 this locality accounted for about 80 per cent of the total spawn deposition in this sub-district, but in 1957 it produced only about 40 per cent of the total. A small increase in deposition occurred in Area 26. In Area 27 no spawning was reported in 1956; however, in 1957 a small amount again was found.

In the Boundary Bay region, 2.1 miles of spawn were located in 1957, considerably less than the 15.6 miles found in 1955, the only other year in which spawning was reported there.

DISCUSSION

The status of the major B.C. herring stocks will now be discussed in the light of information derived from data in the previous sections.

In 1956–57, herring in British Columbia were generally less numerous than in the previous season and below the average for the past five years. The total catch was only 70 per cent of the record 1955–56 catch and 90 per cent of the average catch for 1951–52 to 1956–57. Catches in all sub-districts were below average except in the northern, lower Queen Charlotte Islands, and lower central sub-districts, where they were slightly above average. The greatest declines in catch occurred in the lower west coast and upper Queen Charlotte Islands sub-districts. Spawn deposition in 1957 was only 74 per cent of the 1956 deposition, well below average. Marked decreases in the amount of spawn deposited occurred in all sub-districts except the northern, upper and lower east coast sub-districts. In the first of these, spawn deposition increased considerably in 1957, but in the other two only slightly.

In the upper Queen Charlotte Islands sub-district there was a marked decline in catch for the second successive year; no spawning was reported for the third year in succession. In 1953–54, the first year this area was fished, the catch amounted to 26,600 tons and availability was very high; in 1954–55, while the catch (21,800 tons) was almost as large as in the previous year, considerably greater effort was required to take it; in 1955–56 the catch was sharply reduced to 6,458 tons, and was accompanied by a further decline in availability; in 1956–57 the catch was again markedly reduced, amounting to only 1,276 tons, and availability also was very sharply down. In 1954, 1.4 miles of spawn were reported, but in succeeding years only insignificant amounts of spawn were found. Thus, assuming the same proportion of the population was available to the fishery each year, it appears that a sharp decline in abundance has occurred in this area in the last four years.

One reason for the decline undoubtedly lies in the relative strengths of the year-classes which contributed to these fisheries. In 1953–54 the 1949 year-class as V-year-old fish contributed almost one-half the catch; its contribution was over twice as large as that made by the 1951 year-class as III-year fish, the 1950 class as IV-year fish, or the 1948 year-class as VI-year fish. In 1954–55, catch was maintained at a high level by the strong entry of the 1951 year-class which, as IV-year fish, provided over one-third of the catch, and almost twice as many fish as either the 1950 year-class or the 1949 year-class, which for VI-year-old fish made a relatively substantial contribution. The catch of the 1952 year-class as III-year-olds was only one-third the size of the catch provided by the 1951 year-class the previous year. In 1955–56 the 1951 year-class, as V-year fish, provided about one-third of the season's reduced catch; its contribution was about twice that provided by the 1953, 1952, or the 1950 year-classes. The contribution of the 1953 year-class as III-year fish was only about one-fifth of the contribution made by the 1951 year-class at the same age. In 1956–57 the 1951 year-class, now at age VI, was again the dominant contributor to the very reduced catch. The 1954 year-class as III-year fish made a very poor showing, contributing about one-twentieth the amount the 1951 year-class did at age III.

Thus it would appear that the 1949 year-class was very strong and the 1951 year-class of above average strength. The 1952 and 1953 year-classes were weak, and the 1954 year-class very weak. Thus the good catches of 1953–54 and 1954–55 were the result of large contributions by two strong year-classes—the 1949 and the 1951. The sharply declining catches of the next two seasons, although partially sustained by the remnants of the 1951 year-class, resulted from the successive recruitment of three weak year-classes.

In the lower Queen Charlotte Islands sub-district, the catch, although slightly above average, was only a little over one-third the phenomenally large catch of the preceding

season. Spawn deposition was sharply reduced. The very large catch of 1955–56 resulted from the extremely large contribution of the very strong 1951 year-class as V-year-old fish. This year-class provided almost two-thirds of the catch. In 1956–57 this year-class contributed over one-third of the catch, over two to three times as much as any of the younger year-classes. The recent decrease in abundance in this population is explained by the appearance of three relatively weak year-classes, those of 1952, 1953, and 1954. The decline in catch would have been greater had it not been for the large contribution for VI-year-old fish of the strong 1951 year-class. As this year-class cannot be expected to make a substantial contribution as VII-year-old fish, a further sharp decline will probably occur in 1957–58.

The catch in the northern sub-district reached the level of the quota for the first time in three years. Spawn deposition also showed a substantial increase in this region. The increase in abundance appears to be due to the above-average strength of the 1953 year-class (IV-year fish). The strong 1951 year-class also made a good contribution as VI-year-olds. The increase in catch may also have been influenced by the change in fishing-grounds. In 1955–56 the fishery centred in Tuck Inlet and Morse Basin and may have been dependent more on local populations. In 1956–57, on the other hand, the fishery centred in Hecate Strait, and tag returns suggest that it was dependent on the major northern population normally fished around Porcher Island.

In the upper central sub-district, while catch increased considerably over 1955–56, it still remained well below average. Spawn deposition, although slightly greater than in 1956, remained at a very low level. It would appear, therefore, that although abundance has increased slightly, it is still well below average. The increase in abundance may be traced to the strength of the 1954 year-class. This year-class may be of average strength in contrast to the two preceding year-classes, which were weak. This year-class, while probably not as strong as the 1951 year-class and definitely not as strong as the 1947 year-class, appears stronger than any of the remaining recent year-classes. The 1955 year-class, which made a strong contribution as II-year fish in 1956–57, may possibly turn out to be as strong as the 1954 year-class.

In the lower central sub-district, the catch, although about average for the last five years, was only about two-thirds as large as in 1955–56. Spawn deposition showed a marked decline for the second year in succession and was about 40 per cent less than in 1956. The strong 1951 year-class, although it made a contribution above average for VI-year fish, was too old to sustain the level of abundance. The 1952 and 1953 year-classes, V- and IV-year-old fish, were relatively weak. The 1954 year-class, as in the upper central sub-district, appears relatively strong, although probably not as strong as the 1951 year-class. The 1955 year-class made an excellent showing as II-year-old fish, particularly in the more southern areas of the sub-district. There is the possibility, therefore, that abundance may increase in 1957–58.

The catch in the upper east coast sub-district was the largest recorded for this region. A substantial summer fishery (13,584 tons) occurred in 1956 off the entrance to Queen Charlotte Strait. The regular winter fishery, however, contributed only about another 1,300 tons, well below average. Spawn deposition decreased fairly sharply from the 1955–56 level, but was probably not greatly below average. As the available evidence suggests that the summer-fished stocks were of upper east coast origin, it would appear that the level of abundance in this population was fairly high in 1956–57. The strong 1951 year-class, while it by no means dominated the summer or winter fisheries, made very strong contributions to both. The 1952 year-class appears to be stronger in this population than the 1953 year-class. The 1954 year-class made a relatively good contribution to both the summer and winter fisheries and appears to be stronger than the 1953 year-class, although probably not as strong as either the 1952 or 1951 year-classes. As the 1955 year-class shows prospects of being of average strength, abundance may remain at a reasonably high level in 1957–58.

In the middle east coast sub-district, the catch, although almost double the 10,000-ton quota, was well below the 1955–56 catch, and slightly below the average catch for the past five years. Spawn deposition was only a little more than 50 per cent of the 1956 deposition. Abundance in 1956–57 declined from the high level of the past few years and now is probably not above average. The 1952 year-class appears to have been the last of a succession of three strong year-classes. The 1953 year-class was below average in strength and the 1954 year-class of probably average strength. No great increase in abundance is expected in 1957–58.

In the lower east coast sub-district, while the quota was again exceeded, the catch was the smallest for the past five seasons. Spawn deposition was about average, approximately the same as in 1955–56. The suggested moderate decline in abundance has probably resulted from the below-average contribution of the relatively weak 1953 year-class as IV-year-old fish. The 1954 year-class appears to be of at least average strength. No marked change in abundance is foreseen in this population.

Both catch and spawn deposition were at a low level in the lower west coast sub-district in 1956–57. The catch was the smallest ever recorded from this region. Spawn deposition, while below average, was greater than in some past years. The newly recruited 1954 year-class appeared to be weak, and the 1953 year-class, although it made at least an average contribution as III-year fish in 1955–56, made a poor showing as IV-year fish this past season. Little increase is looked for in 1957–58 unless the 1955 year-class is stronger than expected.

In the upper west coast sub-district there was again no appreciable fishery. Spawn deposition, while less than in 1956, was still above average. Abundance would appear to be at a relatively high level in this population, but the fish have not become available to the fishermen because of late inshore movement.

ACKNOWLEDGMENT

Each year, through their co-operation in many ways, the fishing companies, herring fishermen, and officers of the Federal Department of Fisheries materially contribute to the success of the British Columbia herring investigation. Their contributions are gratefully acknowledged. Special thanks are due to the various members of the staff of the Biological Station, Nanaimo, B.C., whose advice and effort attend these investigations.

This report continues a series published until 1956 under the auspices of the British Columbia Department of Fisheries. Following the reorganization of certain Provincial Government services, the British Columbia Department of Recreation and Conservation has kindly consented to publish this report.

SUMMARY

Although the 1956–57 tag returns were fewer in number and were attended by more uncertainty as to the most probable area of recovery, they confirmed once again the relative discreteness of the populations as now defined.

Fish from the upper Queen Charlotte Islands population, as in 1955–56 but in contrast to 1954–55, showed the greatest tendency to wander from the sub-district of tagging. Fish from the northern population, in contrast to 1955–56 but as in 1954–55, showed a relatively high " homing " tendency. The 1956–57 returns from fish tagged in this sub-district provide some confirmation of the assumption that the 1956–57 fishery, although centred in Hecate Strait, was dependent on the main northern stock, while the 1955–56 fishery centred in Tuck Inlet and Morse Basin depended to a larger degree on local untagged stocks. In all other populations from which adequate tag returns were available, the proportion of recoveries from the area of tagging followed the average pattern.

The tag recoveries from summer fisheries in 1956–57 and in two previous seasons, although relatively few in number, suggest that in most areas the same stocks are fished in summer as in winter. However, the degree of intermingling with adjacent stocks is greater in summer than in winter.

The total catch in 1956–57 was 177,087 tons, the lowest since 1947–48. Of this total, 30,579 tons were taken in a summer fishery. In the summer fishery, 44 per cent of the catch came from the upper east coast sub-district, 28 per cent from the northern sub-district, and 13 per cent from the lower east coast sub-district. The remaining 15 per cent came from small fisheries in the lower west coast, upper and lower central, middle east coast, and upper Queen Charlotte Islands sub-districts. In the regular winter fishery, catches were below average in all sub-districts, except the northern, lower Queen Charlotte Islands, and lower central. The greatest declines occurred in the lower west coast and upper Queen Charlotte Islands sub-districts. Spawn deposition in 1957 was the lowest recorded, and represented a reduction of 30 per cent from the 1956 level. The greatest decreases occurred in the lower Queen Charlotte Islands, middle east coast, upper west coast, lower central, upper east coast, and lower west coast sub-districts. A substantial increase in spawn deposition occurred in the northern sub-district, and slight increases in the lower east coast and upper central sub-districts.

In 1956–57, herring were relatively less abundant than in 1955–56 in the upper and lower Queen Charlotte Islands, lower central, middle and lower east coast, and upper and lower west coast sub-districts.

In 1956–57 the strong 1951 year-class, although it made relatively substantial contributions for the VI-year-old fish to the catches in some sub-districts, was too old to sustain the level of abundance in any population. In the upper and lower Queen Charlotte Islands sub-districts, the low level of abundance is associated with the weakness of the year-classes providing fish of ages III, IV, and V (the 1954, the 1953, and the 1952 year-classes respectively). In the lower central sub-district the 1952 and 1953 year-classes were relatively weak, and had the 1954 year-class not been of at least average strength, abundance would have been lower. In the middle east coast sub-district, the 1952 year-class appears to have been the last of a succession of three strong year-classes. The 1953 year-class (IV-year fish in 1956–57) was of below average strength, but the 1954 year-class (age III) may be of average strength. In the lower east coast sub-district the decrease in abundance was relatively slight and may be traced to the below-average strength of the 1953 year-class (IV-year-old fish). The 1954 year-class was probably of average strength. In the lower west coast sub-district, in common with other Southern British Columbia populations, newly recruited fish of age III formed the bulk of the population. In 1956–57 the dominant year-class (that of 1954) was very weak. The 1953 year-class (age IV) made a poor contribution, although it had appeared to be of average strength the previous season.

Only in the northern sub-district did fish appear to be definitely more abundant than in 1955–56. In this sub-district the 1953 year-class (age IV) appeared to be of about average strength and the 1954 year-class (age III) of probably average strength.

In the upper central sub-district, although abundance showed probably a slight increase over the 1955–56 level, it still remained well below average. In this sub-district the 1954 year-class was probably of average strength, while the two preceding year-classes were weak.

In 1956–57, fish of each age were somewhat larger than in 1955–56 and larger than the average for the last ten years in the upper and lower Queen Charlotte Islands, northern, upper east coast, and lower west coast populations. In the lower central and the upper west coast sub-districts, the fish were smaller than average, and the lower central fish were smaller than in 1955–56. Fish in the lower and middle east coast sub-

districts were similar in size to those of the previous year and close to the ten-year averag
Females continued to outnumber males in all populations.

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* Reprints were published in year following the date of publication of report.

Table I.—Catch and Availability by Sub-district for the 1956–57 and 1955–56 Seasons

Sub-district	Season	Catch, 1956–57	Catch, 1955–56	Average Catch, 1951–52 to 1956–57[1]	Catch per Unit of Effort, 1956–57	Catch pe Unit of Effort, 1955–56
Upper Queen Charlotte Islands—						
Area 1	Summer[2]	344	———	———	35	—
Area 2AB	Winter[3]	1,276	6,458	14,033	15	58
Area 2AW	Winter	117	———	———	—	...
Lower Queen Charlotte Islands—						
Area 2BE	Winter	25,626	85,609	24,987	33	138
Area 2BW	Winter	512	———	———	19	—
Northern	Summer	8,478	———	———	58	—
	Winter	22,983	11,429	28,306	52	22
Upper central—Area 6	Summer	355	———	———	14	—
	Winter	5,043	1,869	8,382	38	—
Lower central—Areas 7 to 10	Summer	792	———	———	—	—
	Winter	29,323	46,391	27,962	30	98
Upper east coast	Summer	13,584	———	———	45	—
	Winter	1,312	920	5,266	24	46
Middle east coast	Summer	906	———	———	14	...
	Winter	17,753	29,652	20,401	73	47
Lower east coast	Summer	4,007	———	———	13	...
	Winter	39,164	48,709	46,567	56	59
Lower west coast	Summer	2,114	———	———	19	—
	Winter	2,858	18,847	13,837	42	88
Upper west coast	Winter	541	560	7,249	44	62
Total (tons)	Summer	30,579	———	———	—	—
	Winter	146,508	250,444	196,486	—	—

[1] Catches in 1952–53 omitted.

[2] Summer fishery, June 1st to September 30th, except in lower east coast sub-district where the opening date is May 1st.

[3] Winter fishery, October 1st to February 5th, in District 3 and to March 10th in District 2. Because of a delay in reaching a price agreement, the season started on December 4th in 1956–57.

Table II.—Number of Tags Recovered by Plant Crews, according to Area of Tagging and Probable Sub-district of Recovery, for the 1956–57 Fishing Season

SUMMER FISHERY, 1956–57

Sub-district and Area of Tagging	Tagging Code	Year of Tagging	Probable Sub-district of Recovery														Total
			Upper Queen Charlotte Islands	Lower Queen Charlotte Islands	Northern	Upper Central	Lower Central	Upper East Coast	Middle East Coast	Lower East Coast	Lower West Coast	Upper West Coast	Northern B.C. (District 2)	Middle and Lower East Coast	?	
Lower Queen Charlotte Islands																	
Area 2BE	18S	1954													1	1	
Northern																	
Area 4	16AA	1952			1											1	
	18Q	1954			1											1	
Area 5	18N	1954			1											1	
Lower Central																	
Area 7	16X	1952							1							1	
	17FF	1953						1								1	
	17HH	1953			1											1	
	17KK	1953						1								1	
Middle East Coast																	
Area 13	19A	1955						4	1	4						9	
	20A	1956						2	2	1	1			1		7	
Area 14	19B	1955						2	2							4	
	19C	1955							1							1	
	20B	1956							3	7	1			2		13	
	20C	1956						1	9	8				4		22	
	20D	1956							1	3	1					4	
	20E	1956							11	16	1			4		32	
	20F	1956						2	4	26	1			5		38	
Area 15	18A	1954							2	2						4	
	19D	1955						2	2	5				1		10	
	19E	1955						1	1							2	
Lower East Coast																	
Area 17A	17E	1953							1							1	
	18C	1954								2						2	
	19G	1955								1				1		2	
	20H	1956							6	15				4		25	
Area 17B	18B	1954								2						2	
	19H	1955							1	1						2	
	19K	1955								2						2	
	20J	1956							1	24						25	
	20K	1956							3	42	4			2		51	
Area 18	15F	1951								1						1	
	17J	1953							1	1						2	
	18E	1954								1						1	
	19M	1955								1						1	
Upper West Coast																	
Area 25											1					1	
San Juan Islands, U.S.A.																	
Quilcene Bay		1956								1	1					2	

Table II.—Number of Tags Recovered by Plant Crews, according to Area of Tagging and Probable Sub-district of Recovery, for the 1956–57 Fishing Season—Continued

WINTER FISHERY, 1956–57

Sub-district and Area of Tagging	Tagging Code	Year of Tagging	Probable Sub-district of Recovery													Total
			Upper Queen Charlotte Islands	Lower Queen Charlotte Islands	Northern	Upper Central	Lower Central	Upper East Coast	Middle East Coast	Lower East Coast	Lower West Coast	Upper West Coast	Northern B.C. (District 2)	Middle and Lower East Coast	?	
Upper Queen Charlotte Islands																
Area 2AE	18T	1954	4	—	2	—	—	—	—	—	—	—	—	—	—	6
	18U	1954	13	1	8	—	—	—	—	—	—	—	—	—	—	22
	18W	1954	1	—	1	—	—	—	—	—	—	—	—	—	—	2
Lower Queen Charlotte Islands																
Area 2BE	16CC	1952	—	10	2	—	—	—	—	—	—	—	1	1	—	14
	17QQ	1953	—	13	3	—	1	—	—	—	—	—	1	—	—	18
	17RR	1953	—	10	1	—	1	—	—	—	—	—	—	—	—	12
	18S	1954	—	29	7	—	2	—	—	—	—	—	3	—	.	41
Northern																
Area 4	16Z	1952	—	—	1	—	—	—	—	—	—	—	1	—	—	2
	16AA	1952	—	—	1	—	—	—	—	—	—	—	—	—	—	1
	17MM	1953	—	1	6	—	1	—	—	—	—	—	—	—	—	8
	17NN	1953	—	1	2	—	—	—	—	—	—	—	1	—	1	5
	17PP	1953	—	—	1	—	1	—	—	—	—	—	—	—	—	2
	18P	1954	—	—	1	—	—	—	—	—	—	—	—	—	—	1
	18Q	1954	—	1	10	—	—	—	—	—	—	—	—	—	—	11
	18R	1954	—	1	24	—	2	—	—	—	—	—	—	—	—	28
Area 5	18N	1954	—	1	13	—	6	—	1	—	—	—	2	—	—	23
Upper Central																
Area 6	14BB	1950	—	—	—	1	—	—	—	—	—	—	—	—	—	1
	15V	1951	—	—	1	—	—	—	—	—	—	—	—	—	—	1
	17LL	1953	—	—	—	—	4	—	—	—	—	—	—	—	—	4
	18M	1954	—	2	—	—	5	—	—	—	—	—	1	1	.	9
Lower Central																
Area 7	15AA	1951	—	—	—	—	2	—	—	—	—	—	—			2
	15BB	1951	—	—	—	—	4	—	—	—	—	—	2	1		7
	16U	1952	—	1	—	—	3	—	—	—	—	—	—	—		4
	16W	1952	—	—	—	—	10	—	—	—	—	—	1	—		11
	16X	1952	—	—	—	—	3	—	—	—	—	—	—	—	1	4
	16Y	1952	—	—	—	—	13	—	—	—	—	—	1	.		14
	17EE	1953	—	1	3	—	15	—	—	—	—	—	2	—		21
	17FF	1953	—	—	—	—	23	—	—	—	—	—	1	—		24
	17GG	1953	—	1	—	—	11	—	—	—	—	—	1	—		13
	17HH	1953	—	—	.	—	4	—	.	—	.	—	—	—		4
	17II	1953	—	—	.	—	4	—	—	—	—	—	.	—		4
	17KK	1953	.	—	—	—	5	.	—	—	—	—				5
	18J	1954	—	—	—	—	13		—	—	—	—	1			14
	18K	1954	—	—	—	—	15	—	—	—	—	—	1	1		17
	18L	1954	—	3	—	—	9	—	1	—	—	—	1	1		15
Area 10	15CC	1951	—	—	—	—	1	—	—	—	—	—	—	.		1
Upper East Coast																
Area 12	17DD	1953	—	—	—	—	—	14	—	—	—	—	—	—	4	18
Middle East Coast																
Area 13	19A	1955	—	—	—	—	—	—	6	2	—	—	1	57	6	72
	20A	1956	—	—	—	—	1	—	45	6	—	—	—	206	16	274
Area 14	14A	1950	—	—	—	—	—	—	—	—	—	—	—	1		1
	16A	1952	—	—	—	—	—	—	2	1	—	—	—	2	1	6
	17B	1953	—	—	—	—	—	—	—	—	—	—	—	1	—	1
	18B	1954	—	—	—	—	—	—	—	—	—	—	—	1	—	1
	19B	1955	—	—	—	—	—	—	—	1	—	—	—	24	1	26
	19C	1955	—	—	—	—	—	—	1	2	—	—	—	5	1	9

Table II.—Number of Tags Recovered by Plant Crews, according to Area of Tagging and Probable Sub-district of Recovery, for the 1956–57 Fishing Season—Continued

WINTER FISHERY, 1956–57—*Continued*

Sub district and Area of Tagging	Tagging Code	Year of Tagging	Probable Sub-district of Recovery													Total
			Upper Queen Charlotte Islands	Lower Queen Charlotte Islands	Northern	Upper Central	Lower Central	Upper East Coast	Middle East Coast	Lower East Coast	Lower West Coast	Upper West Coast	Northern B.C. (District 2)	Middle and Lower East Coast	?	
Area 14	20B	1956	.	..	..	.	..	.	1	1			...	10	.	12
	20C	1956	—	—	—	—	—	—	20	7	—	—	—	113	5	145
	20D	1956	—	—	—	—	—	—	13	1	—	—	—	53	5	72
	20E	1956	—	—	—	—	1	—	10	6	—	—	—	77	4	98
	20F	1956	—	—	—	—	1	—	13	9	1	—	—	88	6	118
Area 15	14B	1950	—	—	—	—	—	—	—	—	—	—	—	1	—	1
	14C	1950	—	—	—	—	—	—	—	—	—	—	—	1	—	1
	15A	1951	—	—	—	—	—	—	1	—	—	—	—	3	—	4
	15B	1951	—	—	—	—	—	—	—	—	—	—	—	3	—	3
	17A	1953	—	—	—	—	—	—	2	—	—	—	—	5	—	7
	18A	1954	—	—	—	—	—	—	2	2	—	—	—	12	1	17
	19D	1955	—	—	—	—	2	—	11	2	—	—	—	52	3	71
	19E	1955	—	—	—	—	—	—	14	4	—	—	—	55	3	73
Area 16	20G	1956	—	—	—	—	—	—	—	—	—	—	—	1	—	1
Lower East Coast																
Area 17A	18C	1954	—	—	—	—	—	—	1	—	—	—	—	2	—	3
	19F	1955	—	—	—	—	—	—	1	2	—	—	—	5	—	8
	19G	1955	—	—	—	—	—	—	—	3	—	—	—	2	—	5
	20H	1956	—	—	—	—	—	—	—	7	—	—	—	23	2	32
Area 17B	18D	1954	—	—	—	—	—	—	—	—	—	—	—	1	—	1
	19H	1955	—	—	—	—	—	—	—	2	—	—	—	4	—	6
	19K	1955	—	—	—	—	—	—	—	—	—	—	—	—	1	1
	20J	1956	—	—	—	—	—	—	—	22	—	—	—	11	—	33
	20K	1956	—	—	—	—	1	—	—	15	—	—	—	27	2	45
Area 18	15F	1951	—	—	—	—	—	—	—	—	—	—	—	1	—	1
	18E	1954	—	—	—	—	—	—	—	1	—	—	—	1	—	2
	18F	1954	—	—	—	—	—	—	—	—	—	—	—	4	—	4
	19L	1955	—	—	—	—	—	—	—	—	—	—	—	2	—	2
	19M	1955	—	—	—	—	—	—	—	—	—	—	—	2	—	2
Lower West Coast																
Area 24	16K	1952	—	—	—	—	—	—	—	—	—	—	—	1	—	1
	17T	1953	—	—	—	—	—	—	—	—	1	—	—	—	—	1
Upper West Coast																
Area 25	18H	1954	—	1	—	—	—	—	—	—	—	—	—	—	—	1
Area 26	16T	1952	—	1	—	—	—	—	—	—	—	—	—	—	—	1
	17AA	1953	—	—	—	—	—	—	—	—	—	1	—	1	—	2
	17BB	1953	—	—	—	—	—	—	—	—	—	1	—	—	—	1
San Juan Islands, U.S.A.																
Holmes Harbor		1955								1				1	1	3
Holmes Harbor		1956												3		3
Quiceene Bay		1956	—	—	—	—	—	—	—	1	—	1	—	5	1	8
Waldron Island		1956	—	—	—	—	—	—	—	—	—	—	—	1	—	1
Locality Unknown		——	—	—	—	—	—	—	—	—	—	—	—	2	—	2

JUVENILE HERRING TAG RECOVERIES

Middle East Coast																
Area 16	19B	1955	—	—	—	—	—	—	—	1	—	—	—	—	—	1
Lower West Coast																
Area 23	17YY	1953												1		1
	17BBB	1953										1				1

Table III.—Probable Numbers of Tags in the Catches during the 1956–57 Season, Based on Magnet Recoveries, Shown by Area of Tagging and Probable Sub-district of Recovery, with Actual Number of Tags[1] in Parentheses.

SUMMER FISHERY, 1956–57

Sub-district and Area of Tagging	Probable Sub-district of Recovery												Grand Total
	Upper Queen Charlotte Islands	Lower Queen Charlotte Islands	Northern	Lower Central	Upper East Coast	Middle East Coast	Lower East Coast	Lower West Coast	Total "Certain"	Northern B.C. (District 2)	Middle and Lower East Coast	?	
Lower Queen Charlotte Islands													
Area 2BE												1	1
												(1)	(1)
Northern													
Area 4			4						4				4
			(2)						(2)				(2)
Area 5			2						2				2
			(1)						(1)				(1)
Lower Central													
Area 7			2		2	1			5				5
			(1)		(2)	(1)			(4)				(4)
Middle East Coast													
Area 13					7	3	7	1	18		1		19
					(6)	(3)	(5)	(1)	(15)		(1)		(16)
Area 14					5	37	69	4	115		17		132
					(5)	(31)	(59)	(4)	(99)		(15)		(114)
Area 15					3	6	8		17		1		18
					(3)	(5)	(7)		(15)		(1)		(16)
Lower East Coast													
Area 17A						8	22		30		6		36
						(7)	(18)		(25)		(5)		(30)
Area 17B						6	84	4	94		2		96
						(5)	(71)	(4)	(80)		(2)		(82)
Area 18						1	5		6				6
						(1)	(4)		(5)				(5)
Upper West Coast													
Area 25								1	1				1
								(1)	(1)				(1)
United States of America													
San Juan Islands							1	1	2				2
							(1)	(1)	(2)				(2)

WINTER FISHERY, 1956–57

Upper Queen Charlotte Islands													
Area 2AE	16	2	14						32				32
	(6)	(1)	(8)						(15)				(15)
Lower Queen Charlotte Islands													
Area 2BE		73	17	4					94	6	1		101
		(47)	(11)	(3)					(61)	(5)	(1)		(67)
Northern													
Area 4		6	58	4					68	1		2	71
		(4)	(34)	(3)					(41)	(1)		(2)	(44)
Area 5		1	18	9		1			29	3			32
		(1)	(13)	(6)		(1)			(21)	(2)			(23)

[1] No magnet efficiency tests were carried out at the Butedale or Port Albion plants. Therefore, in calculating the probable number of tags, recoveries at these plants were omitted. Hence the actual number of recoveries in Table III will not agree in all cases with those in Table II.

Table III.—Probable Numbers of Tags in the Catches during the 1956–57 Season, Based on Magnet Recoveries, Shown by Area of Tagging and Probable Sub-district of Recovery, with Actual Number of Tags[1] in Parentheses—Continued.

WINTER FISHERY, 1956–57—*Continued*

Sub-district and Area of Tagging	Probable Sub-district of Recovery												
	Upper Queen Charlotte Islands	Lower Queen Charlotte Islands	Northern	Lower Central	Upper East Coast	Middle East Coast	Lower East Coast	Lower West Coast	Total "Certain"	Northern B.C. (District 2)	Middle and Lower East Coast	?	Grand Total
Upper Central													
Area 6		1	2	10					13	1	2		16
		(1)	(1)	(8)					(10)	(1)	(1)		(12)
Lower Central													
Area 7		8	3	137		1			149	13	4	1	167
		(6)	(2)	(105)		(1)			(114)	(11)	(3)	(1)	(129)
Area 10				1					1				1
				(1)					(1)				(1)
Upper East Coast													
Area 12					16				16			4	20
					(14)				(14)			(4)	(18)
Middle East Coast													
Area 13				1		53	9		63	1	310	17	391
				(1)		(51)	(8)		(60)	(1)	(251)	(15)	(327)
Area 14				3		62	32		97		446	15	558
				(2)		(59)	(27)		(88)		(363)	(14)	(465)
Area 15				3		31	10		44	1	157	4	206
				(2)		(30)	(8)		(40)	(1)	(129)	(4)	(174)
Area 16											1		1
											(1)		(1)
Lower East Coast													
Area 17A						2	13		15		37	1	53
						(2)	(12)		(14)		(31)	(1)	(46)
Area 17B							45		45		52	2	99
							(39)		(39)		(42)	(2)	(83)
Area 18							1		1		13		14
							(1)		(1)		(12)		(13)
Lower West Coast													
Area 24											1		1
											(1)		(1)
Upper West Coast													
Area 26											1		1
											(1)		(1)
United States of America													
San Juan Islands							2		2		15	2	19
							(2)		(2)		(12)	(2)	(16)

JUVENILE HERRING TAG RECOVERIES

Middle East Coast													
Area 16							1		1				1
							(1)		(1)				(1)
Lower West Coast													
Area 23											3		3
											(1)		(1)

Table IV.—The Average Percentage Age Composition of Herring Sampled from Each Major Population or Sub-district during the 1956–57 Winter Fishing Season and by Months for Each Statistical Area during the 1956 Summer Fishing Season.

(Comparable data for the previous four seasons are also shown together with the ten-year average for the seasons 1946–47 to 1955–56, inclusive. Dominant year-classes are given in italics.)

WINTER FISHERY

Population and Fishing Season	In Year of Age								
	I	II	III	IV	V	VI	VII	VIII	IX+
West Coast, Queen Charlotte Islands									
Area 2AW—1956–57[1]	——	——	*63.41*	31.71	2.44	2.44	——	——	——
Area 2BW—1956–57[1]	——	1.11	*40.60*	17.63	13.22	15.34	9.92	2.18	——
Upper East Coast, Queen Charlotte Islands[2]									
1952–53[3]	——	——	——	——	——	——	——	——	——
1953–54	0.05	2.42	*27.18*	21.27	*35.10*	10.66	2.33	0.68	0.29
1954–55	——	7.81	13.77	*40.90*	18.07	14.81	4.18	0.29	0.10
1955–56	0.10	13.81	*24.71*	*20.49*	*23.85*	9.92	5.22	1.34	0.56
1956–57	——	6.04	*24.94*	*21.39*	15.88	*22.26*	5.94	2.94	0.63
Lower East Coast, Queen Charlotte Islands[4]									
1952–53[3]	——	——	——	——	——	——	——	——	——
1953–54	——	——	*38.24*	*38.24*	8.82	11.76	——	2.94	——
1954–55[5]	——	——	——	——	——	——	——	——	——
1955–56	——	0.16	15.39	9.82	*62.25*	8.62	2.89	0.70	0.17
1956–57	0.20	*20.47*	*23.42*	15.71	9.71	*27.60*	2.35	0.39	0.14
Northern									
Ten-year average	0.02	5.57	26.27	35.80	23.18	6.77	1.93	0.38	0.08
1952–53	——	1.27	*34.34*	*23.58*	*25.72*	11.03	0.98	0.08	——
1953–54	——	1.96	*28.35*	*29.37*	*23.80*	13.33	2.54	0.58	0.06
1954–55	——	2.78	4.90	*70.78*	15.32	5.02	1.04	0.15	——
1955–56	——	8.85	*56.30*	9.77	20.84	3.28	0.62	0.19	0.14
1956–57	——	11.31	18.39	*39.96*	12.88	15.85	1.31	0.28	0.03
Upper Central									
Ten-year average	0.22	19.81	31.04	23.47	18.01	6.01	1.11	0.24	0.10
1952–53	0.70	6.94	*24.74*	*24.39*	*28.49*	14.06	0.68	——	——
1953–54	0.42	5.12	*74.47*	14.11	4.93	0.94	——	——	——
1954–55	0.06	12.53	18.82	*63.43*	4.08	0.87	0.21	——	——
1955–56	——	*84.74*	12.72	1.26	1.14	0.15	——	——	——
1956–57	——	*55.14*	*35.11*	6.76	1.88	1.06	0.05	——	——
Lower Central									
Ten-year average	0.34	7.46	29.89	33.37	23.59	4.29	0.82	0.19	0.05
1952–53	0.40	9.14	*28.13*	*24.04*	*26.69*	9.70	1.42	0.48	——
1953–54	0.18	5.52	*70.41*	18.00	4.39	1.32	0.13	——	0.04
1954–55	0.39	5.74	10.20	*69.83*	10.86	2.65	0.33	——	——
1955–56	0.03	7.64	13.76	9.96	*64.71*	3.46	0.38	0.03	0.02
1956–57	0.01	19.61	*47.97*	13.11	7.04	11.56	0.63	0.07	——
Upper East Coast									
Ten-year average	10.49	24.13	33.88	19.34	7.22	3.09	1.12	0.45	0.28
1952–53	——	——	1.14	20.45	*36.36*	28.41	9.09	2.27	2.27
1953–54	0.16	9.31	*65.87*	15.20	6.61	2.32	0.45	0.08	——
1954–55	0.17	4.66	*34.37*	*45.23*	10.10	3.36	1.58	0.54	——
1955–56	——	16.84	17.15	19.45	*41.16*	5.40	——	——	——
1956–57	——	*41.60*	26.10	7.57	7.75	15.41	1.43	0.14	——
Middle East Coast									
Ten-year average	0.29	9.93	38.03	31.17	15.18	4.25	0.91	0.20	0.04
1952–53	0.60	*30.99*	*41.18*	17.00	6.30	3.16	0.66	0.10	——
1953–54	——	2.48	28.59	*40.98*	18.82	6.77	1.91	0.39	0.05
1954–55	——	6.02	*37.71*	*45.88*	8.25	2.01	0.12	——	——
1955–56	——	9.39	13.08	28.68	*39.14*	7.78	1.37	0.40	0.16
1956–57	——	1.22	*42.31*	18.74	23.76	12.43	1.41	0.11	——

[1] No catch in previous seasons.
[2] No samples were obtained prior to the 1952–53 season.
[3] No fishery.
[4] No samples were obtained prior to the 1950–51 season.
[5] No samples obtained.

Table IV.—The Average Percentage Age Composition of Herring Sampled from Each Major Population or Sub-district during the 1956–57 Winter Fishing Season and by Months for Each Statistical Area during the 1956 Summer Fishing Season—Cont'd.

WINTER FISHERY—*Continued*

Population and Fishing Season	In Year of Age								
	I	II	III	IV	V	VI	VII	VIII	IX+
Lower East Coast									
Ten-year average	0.28	3.48	58.25	30.30	6.38	1.07	0.19	0.04	0.01
1952–53	0.12	2.65	*60.53*	32.83	3.25	0.54	0.05	0.03	----
1953–54	----	0.79	*57.98*	34.23	6.18	0.62	0.14	0.04	0.01
1954–55	----	2.81	*57.18*	33.37	6.05	0.50	0.10	----	----
1955–56	----	4.37	*53.07*	29.86	10.70	1.71	0.24	0.05	----
1956–57	0.02	1.12	*74.91*	19.36	2.98	1.37	0.18	0.04	0.02
Lower West Coast									
Ten-year average	0.04	7.71	58.47	26.69	5.74	1.07	0.20	0.06	0.02
1952–53	0.07	8.88	*55.66*	32.86	1.95	0.54	0.04	----	----
1953–54	0.03	2.72	*64.29*	26.71	5.47	0.53	0.04	----	----
1954–55	0.03	16.82	*59.39*	19.81	3.32	0.59	0.03	----	----
1955–56	----	11.89	*63.70*	15.86	7.04	1.29	0.14	0.04	0.05
1956–57	----	2.55	*72.11*	24.83	0.34	0.17	----	----	----
Upper West Coast									
Ten-year average	0.02	3.32	43.44	31.64	15.90	3.83	1.25	0.45	0.15
1952–53	0.26	22.57	*60.74*	14.60	1.35	0.40	0.07	----	----
1953–54	----	----	*46.14*	*41.85*	9.04	2.04	0.94	----	----
1954–55	----	6.24	34.57	*50.40*	6.78	1.68	0.26	0.07	----
1955–56[5]	----	----	----	----	----	----	----	----	----
1956–57	----	----	*51.55*	28.87	15.46	4.12	----	----	----

[5] No samples obtained.

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Population and Fishing Season	In Year of Age									
	I	II	III	IV	V	VI	VII	VIII	XI	X
Upper Central										
Area 6—September, 1956	----	----	13.65	21.19	*29.53*	*30.81*	2.05	2.76	----	----
Lower Central										
Area 8—September, 1956	----	----	14.29	14.29	*26.19*	*40.48*	4.76	----	----	----
Upper East Coast										
Area 12—										
June, 1956	----	----	13.95	23.26	*53.49*	9.30	----	----	----	----
August, 1956	----	3.70	*43.11*	19.66	17.99	13.92	1.62	----	----	----
September, 1956	----	20.41	*44.90*	14.29	12.24	8.16	----	----	----	----
Middle East Coast										
Area 14—										
July, 1953	----	0.86	15.79	*36.89*	*32.19*	11.31	2.96	----	----	----
August, 1953	----	0.90	22.76	*35.78*	*29.71*	8.08	2.42	0.11	0.23	----
September, 1953	----	3.23	23.02	*37.35*	*23.57*	8.40	3.25	1.18	----	----
Area 16—										
June, 1953	0.33	18.73	*39.85*	*30.93*	8.29	2.06	----	----	----	----
July, 1953	----	6.18	*77.32*	15.46	1.03	----	----	----	----	----
Area 14—										
July, 1954	----	0.28	19.48	*52.89*	20.31	6.76	0.28	----	----	----
September, 1956	----	----	2.11	*46.81*	*37.09*	12.36	1.62	----	----	----
Lower East Coast										
Area 17A—										
May, 1956	----	3.63	*39.54*	*28.36*	24.36	4.12	----	----	----	----
June, 1956	----	----	9.57	*44.88*	27.25	16.92	0.67	----	----	0.72
September, 1956	----	----	24.47	*47.34*	20.49	7.70	----	----	----	----
Area 17B—July, 1956	----	0.58	*36.05*	*41.28*	13.37	7.56	0.58	0.58	----	----
Area 18—										
June, 1956	----	0.22	10.92	*43.38*	25.71	16.60	2.27	0.90	----	----
July, 1956	----	15.38	12.74	*38.91*	19.85	10.65	1.74	----	0.37	0.37
September, 1956	----	----	*65.91*	25.00	9.09	----	----	----	----	----
Area 19—September, 1956	----	----	*87.50*	12.50	----	----	----	----	----	----
Lower West Coast										
Area 21—July, 1953	----	----	36.34	*47.25*	13.74	1.57	0.96	----	0.14	----

Table V.—Number of Fish of Each Age (in Millions) in the Catch from Each Population during the 1956–57 Winter Fishing Season and by Months for Each Statistical Area during the 1956 Summer Fishing Season.

(Comparable data for the previous four seasons are also shown. Dominant year-classes are given in italics.)

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Population and Fishing Season	In Year of Age										Total
	I	II	III	IV	V	VI	VII	VIII	IX	X	
West Coast Queen Charlotte Islands											
Area 2AW—1956–57[1]	.. ..	.. ..	*0.77*	0.39	0.03	0.03	—	—	—	—	1.22
Area 2BW—1956–57[1]	—	0.05	*1.65*	0.72	0.54	0.63	0.40	0.09	—	—	4.08
Upper East Coast, Queen Charlotte Islands											
1952–53[2]	—	—	—	—	—	—	—	—	—	—	—
1953–54	0.12	7.43	*83.61*	65.44	*107.98*	32.78	7.17	2.08	0.89	—	307.50
1954–55	.	16.32	28.74	*85.36*	37.71	30.91	8.72	0.60	0.38	..	208.74
1955–56	0.07	9.59	*17.16*	*14.23*	*16.57*	6.89	3.62	0.93	0.39	—	69.45
1956–57	—	0.71	*2.92*	*2.51*	1.86	*2.61*	0.70	0.34	0.07	..	11.72
Lower East Coast, Queen Charlotte Islands											
1952–53[3]	—	—	—	—	—	—	—	—	—	—	—
1953–54	—	—	*7.23*	*7.23*	1.67	2.22	—	0.56	—	—	18.91
1954–55[4]	—	—	—	—	—	—	—	—	—	—	—
1955–56	.. ..	1.05	100.91	64.39	*408.15*	56.52	18.95	4.59	1.11	—	655.67
1956–57	0.44	*45.40*	*51.94*	34.84	21.53	*61.21*	5.21	0.86	0.31	..	221.74
Northern											
1952–53	..	0.23	*6.87*	*4.34*	*4.73*	2.02	0.18	0.02	—	—	18.39
1953–54	..	4.87	*70.77*	*73.33*	*59.42*	33.28	6.34	1.45	0.14	..	249.60
1954–55	..	5.09	8.98	*129.86*	28.11	9.21	1.91	0.27	—	..	183.43
1955–56	..	10.78	*68.57*	11.90	25.38	4.00	0.76	0.23	0.17	..	121.79
1956–57	.. ..	13.93	39.05	*81.70*	25.48	35.37	3.39	0.72	0.08	—	199.72
Upper Central											
1952–53	0.01	0.06	*0.21*	*0.21*	*0.24*	0.12	0.01	—	—	—	0.86
1953–54	0.44	5.30	*77.14*	14.14	5.11	0.97	..	—	—	—	103.10
1954–55	0.63	14.53	21.81	*73.50*	4.73	1.01	0.24	—	—	—	116.45
1955–56	.. ..	*32.12*	4.82	0.48	0.43	0.06	..	—	—	—	37.91
1956–57	—	*42.44*	*27.02*	5.20	1.45	0.82	0.04	—	—	—	76.97
Lower Central											
1952–53	0.04	0.99	*2.66*	*2.14*	*2.17*	0.78	0.09	0.03	..	..	8.90
1953–54	0.41	13.94	*234.14*	66.51	15.85	3.49	0.48	..	0.16	..	334.98
1954–55	0.72	14.26	25.86	*125.38*	19.85	4.63	0.48	..	..	..	191.18
1955–56	0.14	20.74	47.11	36.91	*242.67*	12.59	1.35	0.14	0.11	..	361.76
1956–57	0.05	61.28	*164.24*	45.12	24.76	45.40	2.37	0.20	..	..	343.42
Upper East Coast											
1952–53[5]	—	—	—	—	—	—	—	—	—	—	—
1953–54	0.13	8.60	*60.90*	14.05	6.11	2.15	0.41	0.07	—	—	92.42
1954–55	0.24	9.06	*49.67*	*75.13*	18.15	3.24	0.64	0.22	—	..	156.35
1955–56	—	1.87	1.90	2.16	*4.57*	0.60	..	..	—	..	11.10
1956–57	—	*6.02*	3.78	1.10	1.12	2.23	0.21	0.02	—	..	14.48
Middle East Coast											
1952–53[6]	+	*0.18*	*0.24*	0.10	0.04	0.02	+	+	—	—	0.58
1953–54	—	4.40	*50.42*	*70.08*	27.55	10.47	2.78	0.59	0.07	..	166.36
1954–55	.. ..	15.44	*95.15*	*112.83*	20.03	5.04	0.21	..	..	..	248.70
1955–56	—	28.97	36.00	*73.94*	*96.90*	18.92	3.25	0.91	0.34	..	259.23
1956–57	—	1.78	*61.58*	27.28	34.58	18.09	2.05	0.16	..	..	145.52

[1] No catch in previous seasons.
[2] No catch.
[3] One hundred and eighty-five tons caught; no samples obtained.
[4] Five hundred and fifty tons caught; no samples obtained.
[5] One hundred and three tons caught; samples inadequate.
[6] Eighty-three tons caught; 45 tons by seine shown here but not in previous Reports.

Table V.—Number of Fish of Each Age (in Millions) in the Catch from Each Population during the 1956–57 Winter Fishing Season and by Months for Each Statistical Area during the 1956 Summer Fishing Season—Continued.

WINTER FISHERY—*Continued*

Population and Fishing Season	In Year of Age										Total
	I	II	III	IV	V	VI	VII	VIII	IX	X	
Lower East Coast											
1952–53	0.12	2.00	*51.59*	30.51	2.98	0.51	0.06	0.03			87.80
1953–54		3.54	*283.14*	167.41	29.55	3.02	0.67	0.20	0.09		487.62
1954–55		13.55	*261.95*	151.56	26.41	2.22	0.31				456.00
1955–56		20.75	*246.47*	137.66	48.26	7.36	1.07	0.16			461.73
1956–57	0.08	4.45	*297.91*	76.99	11.85	5.45	0.72	0.16	0.08		397.69
Lower West Coast											
1952–53[7]		0.04	*0.12*	0.07	+	+	+				0.23
1953–54	0.27	7.92	*194.15*	86.22	18.36	1.98	0.58	0.21	0.12		309.81
1954–55	0.02	11.86	*41.89*	13.97	2.34	0.42	0.02				70.52
1955–56		25.00	*129.16*	30.65	8.36	1.47	0.27	0.07	0.03		195.01
1956–57		0.63	*17.75*	6.11	0.08	0.04					24.61
Upper West Coast											
1952–53[8]											
1953–54			*42.42*	*39.80*	9.03	2.19	1.02				94.46
1954–55		3.95	21.62	*31.07*	4.32	0.92	0.17	0.04			62.09
1955–56[8]											
1956–57			*2.44*	1.37	0.73	0.20					4.74

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Upper Central											
Area 6—September, 1956			0.10	0.15	*0.21*	*0.22*	0.01	0.02			0.71
Lower Central											
Area 8—September, 1956			0.41	0.41	*0.76*	*1.17*	0.14				2.89
Upper East Coast											
Area 12—											
June, 1956			0.98	1.63	*3.75*	0.65					7.01
August, 1956		3.64	*42.40*	19.34	17.70	13.69	1.59				98.37
September, 1956		1.00	*2.19*	0.70	0.60	0.40					4.89
Middle East Coast											
Area 14—											
July, 1953		0.03	0.53	*1.23*	*1.07*	0.38	0.10				3.34
August, 1953		0.11	2.76	*4.34*	*3.60*	0.98	0.29	0.01	0.03		12.12
September, 1953		1.40	10.00	*16.22*	*10.23*	3.65	1.41	0.51			43.42
Area 16—											
June, 1953	0.01	0.65	*1.39*	*1.08*	0.29	0.07					3.49
July, 1953		0.19	*2.42*	0.48	0.03						3.12
Area 14—											
July, 1954		0.08	5.28	*14.34*	5.51	1.83	0.08				27.12
September, 1956			0.12	*2.56*	*2.03*	0.68	0.09				5.48
Lower East Coast											
Area 17A—											
May, 1956		0.01	*0.13*	*0.09*	0.08	0.01					0.32
June, 1956			0.44	*2.06*	1.25	0.78	0.03				4.56
September, 1956			0.33	*0.64*	0.28	0.10					1.35
Area 17B—July, 1956		0.04	*2.34*	*2.68*	0.87	0.49	0.04	0.04			6.50
Area 18—											
June, 1956		0.01	0.72	*2.86*	1.69	1.09	0.15	0.06			6.58
July, 1956		0.40	0.33	*1.02*	0.52	0.28	0.05		0.01	0.01	2.62
September, 1956			*2.71*	1.03	0.37						4.11
Area 19—September, 1956			*1.89*	0.27							2.16
Lower West Coast											
Area 21—July, 1953			6.52	*8.48*	2.47	0.28	0.17		0.03		17.95

[8] No catch.
[7] Twenty-three tons caught; not shown in previous Reports.
[9] Five hundred and sixty tons caught; no samples obtained.

Table VI.—The Average Length in Millimetres of Herring Sampled from Each Major Population or Sub-district during the 1956–57 Winter Fishing Season and by Months for Each Statistical Area during the 1956 Summer Fishing Season.

(Comparable data for the previous four seasons are also shown together with the ten-year average for the seasons 1946–47 to 1955–56, inclusive.)

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Population and Fishing Season	In Year of Age									
	I	II	III	IV	V	VI	VII	VIII	IX	X+
West Coast Queen Charlotte Islands										
Area 2AW—1956–57[1]	.....	.....	191.42	204.15	215.00	227.00	.....	.....	.....	.....
Area 2BW—1956–57[1]	.....	144.00	191.03	206.25	211.58	221.58	230.89	228.50	.....	.....
Upper East Coast, Queen Charlotte Islands										
Ten-year average	109.50	140.58	161.47	179.48	198.92	211.81	223.81	232.70	235.00	253.33
1952–53[2]	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1953–54	122.00	132.53	165.58	175.69	197.14	208.13	216.68	231.09	236.33	262.00
1954–55	.....	147.28	162.59	184.32	201.68	214.50	228.87	243.67	237.00	244.00
1955–56	97.00	139.06	159.54	176.27	200.62	213.52	223.70	231.54	236.50	254.00
1956–57	.....	146.59	171.13	186.59	200.30	214.55	226.67	236.00	243.50	.....
Lower East Coast, Queen Charlotte Islands										
Ten-year average	101.41	151.03	181.05	192.43	202.32	210.70	216.51	223.10	210.00	.....
1952–53[3]	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1953–54	.....	.....	178.85	197.23	204.67	221.25	.....	228.00	.....	.....
1954–55[3]	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1955–56	.....	160.50	186.19	197.74	203.16	215.06	221.92	224.50	.....	.....
1956–57	101.44	153.83	189.83	204.45	211.89	215.04	223.82	226.89	227.17	.....
Northern										
Ten-year average	117.43	145.24	173.78	190.70	202.46	208.69	211.18	217.60	219.35	241.00
1952–53	.....	149.41	182.72	200.95	210.98	215.87	222.00	217.00	.....	.....
1953–54	.....	144.30	177.12	200.98	215.88	223.45	232.42	238.88	230.00	250.00
1954–55	.....	155.58	181.53	193.91	205.37	218.03	222.23	229.00	.....	.....
1955–56	.....	145.40	176.76	190.39	200.03	211.48	217.89	230.67	237.50	.....
1956–57	.....	138.00	179.79	198.26	208.88	216.07	230.02	237.17	247.00	.....
Upper Central										
Ten-year average	109.39	143.43	172.93	188.19	203.16	204.82	210.79	215.12	216.73	.....
1952–53	105.50	149.50	192.96	208.01	215.63	223.44	228.00	.....	.....	.....
1953–54	122.00	146.96	165.24	182.90	198.12	214.00	.....	.....	.....	.....
1954–55	128.00	145.76	162.18	179.17	193.65	188.23	219.33	.....	.....	.....
1955–56	.....	147.11	161.38	170.43	200.29	235.00	.....	.....	.....	.....
1956–57	.....	148.05	177.81	196.08	207.56	217.77	223.00	.....	.....	.....
Lower Central										
Ten-year average	111.38	139.36	170.96	187.39	201.93	208.96	210.79	216.58	220.70	.....
1952–53	119.18	148.11	185.36	200.22	210.70	219.58	226.59	232.62	.....	.....
1953–54	112.22	126.59	158.15	184.06	195.62	203.75	211.67	.....	222.00	.....
1954–55	103.24	132.66	161.46	180.63	194.64	201.68	207.08	.....	.....	.....
1955–56	114.00	143.07	180.16	196.47	205.18	212.24	217.56	208.50	.....	235.00
1956–57	95.00	135.39	171.30	182.81	193.76	206.51	214.60	202.40	.....	.....
Upper East Coast										
Ten-year average	100.06	137.22	160.43	179.28	198.27	213.39	216.69	211.36	252.63	192.25
1952–53[3]	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1953–54	114.25	132.35	154.67	179.24	202.62	224.82	231.91	237.50	.....	.....
1954–55	101.00	135.61	159.13	165.32	178.41	207.92	225.85	227.71	.....	.....
1955–56	.....	115.79	135.67	162.90	198.98	207.37	.....	.....	.....	.....
1956–57	.....	134.39	168.97	189.57	200.62	207.23	214.90	219.00	.....	.....
Middle East Coast										
Ten-year average	103.89	146.68	181.38	197.68	209.86	221.00	228.72	232.57	246.37	246.00
1952–53	107.75	138.73	177.93	199.05	215.77	224.58	228.62	229.00	.....	.....
1953–54	.....	148.32	174.03	196.28	213.68	224.26	230.88	236.33	269.00	.....
1954–55	.....	150.12	176.53	190.15	204.99	215.95	227.67	.....	.....	.....
1955–56	.....	147.03	181.72	198.00	206.06	217.56	226.83	234.36	238.20	246.00
1956–57	.....	153.10	180.62	200.90	209.22	214.66	222.79	240.00	.....	.....

[1] No catch in previous seasons.
[2] No fishing.
[3] No samples obtained.

Table VI.—The Average Length in Millimetres of Herring Sampled from Each Major Population or Sub-district during the 1956–57 Winter Fishing Season and by Months for Each Statistical Area during the 1956 Summer Fishing Season—Continued.

WINTER FISHERY—*Continued*

Population and Fishing Season	In Year of Age									
	I	II	III	IV	V	VI	VII	VIII	IX	X+
Lower East Coast										
Ten-year average	99.51	155.00	187.16	198.63	210.29	218.74	226.13	227.81	232.75	
1952–53	106.50	155.94	183.81	195.96	208.64	214.45	222.80	233.33		
1953–54		151.97	187.22	199.49	210.70	222.89	226.70	227.33	237.00	
1954–55		163.09	188.88	199.58	210.63	225.25	238.33			
1955–56		160.16	186.44	198.36	208.26	215.85	224.08	230.50		
1956–57	99.00	158.67	185.57	197.89	210.98	216.84	223.22	235.50		244.00
Lower West Coast										
Ten-year average	107.06	162.65	186.55	200.61	209.68	219.24	224.87	232.23	236.14	278.00
1952–53	97.00	162.12	184.02	197.83	209.41	219.20	211.00			
1953–54	90.50	160.53	185.34	199.81	211.16	222.52	241.38	239.50	271.00	278.00
1954–55	140.00	164.34	182.31	198.64	210.38	221.81	220.00			
1955–56		165.12	185.74	197.71	204.18	216.46	227.71	233.00	221.00	
1956–57		157.40	187.72	200.97	215.00	232.00				
Upper West Coast										
Ten-year average	100.60	153.72	188.45	201.91	215.35	223.02	229.51	233.91	238.57	230.75
1952–53	99.50	145.86	187.81	199.25	207.10	228.50	233.00			
1953–54			181.01	198.05	210.71	222.64	231.83			
1954–55		153.97	180.52	194.96	210.04	216.21	230.75	236.00		
1955–56[3]										
1956–57			183.68	199.96	211.73	213.25				

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Upper Central										
Area 6—September, 1956			181.60	198.94	210.74	213.96	225.33	229.75		
Lower Central										
Area 8—September, 1956			148.67	167.50	174.27	179.76	184.00			
Upper East Coast										
Area 12—										
June, 1956			181.50	192.20	198.70	207.75				
August, 1956		143.60	175.65	192.67	206.95	210.56	220.50			
September, 1956		146.20	174.73	192.00	191.33	197.25				
Middle East Coast										
Area 14—										
July, 1953		140.50	179.72	201.35	215.01	223.83	234.67			
August, 1953		136.00	182.54	202.61	215.47	225.76	230.95	240.00	269.00	
September, 1953		147.80	177.54	200.26	214.92	224.06	230.06	237.54		
Area 16—										
June, 1953	109.00	130.46	171.42	195.55	211.65	223.00				
July, 1953		140.17	165.57	191.33	212.00					
Area 14—										
July, 1954		173.00	191.83	204.07	213.29	224.18	231.00			
September, 1956			187.00	205.28	212.98	217.48	227.50			
Lower East Coast										
Area 17A—										
May, 1956		162.83	187.09	197.50	206.98	213.00				
June, 1956			171.93	198.14	206.78	212.06	211.00			229.00
September, 1956			186.26	205.03	212.21	218.18				
Area 17B—July, 1956		160.00	176.02	196.24	209.83	221.85	214.00	244.00		
Area 18—										
June, 1956		163.00	182.19	195.76	203.80	214.30	223.00	222.00		
July, 1956		130.41	182.74	200.35	209.96	214.87	221.00		227.00	222.00
September, 1956			184.48	200.09	205.50					
Area 19—September, 1956			183.36	194.67						

[3] No samples obtained.

Table VII.—The Average Weight in Grams of Herring Sampled from Each Major Population or Sub-district during the 1956–57 Winter Fishing Season and by Months for Each Statistical Area during the 1956 Summer Fishing Season.

(Comparable data for the previous four seasons are also shown together with the ten-year average for the seasons 1946–47 to 1955–56, inclusive.)

WINTER FISHERY

Population and Fishing Season	In Year of Age									
	I	II	III	IV	V	VI	VII	VIII	IX	X+
West Coast Queen Charlotte Islands										
Area 2AW—1956–57[1]	———	———	78.50	100.85	104.00	129.00	———	———	———	———
Area 2BW—1956–57[1]	———	28.00	82.51	113.25	128.67	148.64	168.00	158.00	———	———
Upper East Coast, Queen Charlotte Islands										
Ten-year average	16.50	33.39	53.03	76.54	103.12	126.24	152.20	165.78	157.50	198.00
1952–53[2]	———	———	———	———	———	———	———	———	———	———
1953–54	20.00	25.09	50.84	67.00	95.17	110.89	131.87	154.36	143.33	145.00
1954–55	———	39.93	57.78	85.52	114.52	135.16	163.38	174.33	215.00	200.00
1955–56	13.00	32.03	54.12	74.38	111.42	137.12	154.60	173.46	155.00	249.00
1956–57	———	34.06	64.44	85.58	106.90	131.36	159.11	189.44	201.50	———
Lower East Coast, Queen Charlotte Islands										
Ten-year average	9.11	38.65	77.70	93.82	116.29	129.84	142.11	156.48	129.00	———
1952–53[3]	———	———	———	———	———	———	———	———	———	———
1953–54	———	———	68.00	93.08	105.33	150.75	———	170.00	———	———
1954–55[3]	———	———	———	———	———	———	———	———	———	———
1955–56	———	43.00	87.54	109.14	121.15	147.42	163.11	166.30	———	———
1956–57	11.44	41.11	87.00	119.22	135.13	143.34	164.36	168.67	180.17	———
Northern										
Ten-year average	31.22	42.26	67.33	89.69	112.95	121.26	124.96	135.83	145.15	156.50
1952–53	———	38.82	80.31	110.76	130.68	143.32	157.22	———	———	———
1953–54	———	35.98	71.76	105.91	130.77	145.19	164.32	182.62	193.00	181.00
1954–55	———	40.36	79.53	95.62	114.41	138.24	147.00	154.00	———	———
1955–56	———	37.13	76.33	94.38	113.70	140.48	151.78	170.00	199.00	———
1956–57	———	28.88	74.37	103.36	122.74	136.99	170.56	185.33	200.00	———
Upper Central										
Ten-year average	15.19	38.12	72.28	95.35	117.64	122.24	136.60	148.82	156.87	———
1952–53	10.50	35.05	91.93	118.41	135.96	153.41	169.00	———	———	———
1953–54	20.50	41.83	60.22	85.68	108.21	138.80	———	———	———	———
1954–55	28.00	41.27	64.10	84.16	105.14	97.15	156.67	———	———	———
1955–56	———	40.95	60.03	70.57	112.29	155.00	———	———	———	———
1956–57	———	40.46	77.07	99.06	116.31	132.55	130.00	———	———	———
Lower Central										
Ten-year average	16.15	33.89	68.35	94.23	117.84	131.56	136.41	175.03	144.15	———
1952–53	18.00	35.72	82.37	106.57	126.10	146.07	160.91	169.86	———	———
1953–54	17.44	26.74	53.09	84.18	101.66	115.69	125.50	———	131.00	———
1954–55	14.06	30.49	60.02	85.31	108.54	124.25	126.23	———	———	———
1955–56	15.50	36.03	83.16	110.31	126.40	141.15	155.83	122.00	———	180.00
1956–57	9.00	30.23	69.00	85.34	102.30	125.97	143.81	118.80	———	———
Upper East Coast										
Ten-year average	12.68	40.93	64.42	84.03	115.98	146.95	162.36	157.11	146.44	109.33
1952–53[3]	———	———	———	———	———	———	———	———	———	———
1953–54	17.50	34.90	56.37	85.03	117.04	154.40	157.45	183.00	———	———
1954–55	14.00	32.84	61.17	66.78	86.25	134.53	170.05	186.29	———	———
1955–56	———	17.89	32.97	62.38	116.10	127.16	———	———	———	———
1956–57	———	54.13	70.48	105.69	125.39	139.27	153.70	144.00	———	———
Middle East Coast										
Ten-year average	36.71	49.50	79.71	106.97	130.17	152.43	171.03	184.30	180.25	186.50
1952–53	11.91	29.84	69.59	103.04	134.00	161.45	165.00	156.00	———	———
1953–54	———	42.59	70.65	104.41	142.57	166.83	183.69	195.94	185.00	———
1954–55	———	45.24	79.54	94.34	124.42	144.78	167.00	———	———	———
1955–56	———	42.84	79.54	105.58	120.02	141.82	160.66	177.89	174.80	186.50
1956–57	———	47.19	79.61	117.70	136.98	150.94	171.08	210.00	———	———

[1] No catch in previous season.
[2] No fishing.
[3] No samples obtained.

Table VII.—The Average Weight in Grams of Herring Sampled from Each Major Population or Sub-district during the 1956–57 Winter Fishing Season and by Months for Each Statistical Area during the 1956 Summer Fishing Season—Continued.

WINTER FISHERY—*Continued*

Population and Fishing Season	In Year of Age									
	I	II	III	IV	V	VI	VII	VIII	IX	X+
Lower East Coast										
Ten-year average	11.03	47.58	87.74	107.67	130.68	147.89	167.56	176.95	179.67	———
1952–53	12.83	44.89	76.78	93.56	118.66	135.30	146.40	185.00	———	———
1953–54	———	46.36	88.41	107.69	127.25	148.66	157.50	181.00	186.00	———
1954–55	———	56.64	94.08	113.45	131.96	163.44	178.33	———	———	———
1955–56	———	51.36	85.16	105.53	124.75	140.22	161.92	173.00	———	———
1956–57	10.00	48.80	83.08	104.41	135.27	149.87	162.56	167.50	———	197.00
Lower West Coast										
Ten year average	15.61	53.33	87.67	109.65	129.55	146.17	157.29	171.68	164.75	———
1952–53	8.50	51.67	78.83	100.06	121.18	143.60	123.00	———	———	———
1953–54	8.50	53.72	85.55	106.65	126.75	148.35	165.75	155.00	———	———
1954–55	37.00	57.83	83.06	107.68	124.91	151.40	131.00	———	———	———
1955–56	———	57.40	85.99	106.64	119.25	138.89	144.00	———	140.00	———
1956–57[4]	———	———	———	———	———	———	———	———	———	———
Upper West Coast										
Ten-year average	10.20	43.52	88.74	111.98	137.25	156.11	171.60	184.14	185.80	180.00
1952–53	9.75	36.23	82.27	100.25	114.70	158.50	168.00	———	———	———
1953–54	———	———	77.41	98.51	123.85	143.25	145.00	———	———	———
1954–55	———	46.44	84.59	104.91	134.67	141.86	180.67	174.00	———	———
1955–56[3]	———	———	———	———	———	———	———	———	———	———
1956–57	———	———	83.48	109.93	135.73	131.75	———	———	———	———

SUMMER FISHERY

Upper Central										
Area 6—September, 1956	———	———	86.80	122.00	153.51	161.42	195.33	203.00	———	———
Lower Central										
Area 8—September, 1956	———	———	44.50	64.33	69.09	76.35	79.00	———	———	———
Upper East Coast										
Area 12—										
June, 1956	———	———	85.50	107.40	115.61	137.00	———	———	———	———
August, 1956	———	42.20	81.25	110.88	136.18	146.50	157.50	———	———	———
September, 1956	———	40.80	80.23	111.71	118.50	125.00	———	———	———	———
Middle East Coast										
Area 14—										
July, 1953	———	34.00	77.03	112.91	139.65	160.21	176.17	———	———	———
August, 1953	———	31.89	83.33	117.53	146.40	168.75	180.82	210.00	185.00	———
September, 1953	———	40.67	78.14	117.00	151.80	175.33	192.45	209.54	———	———
Area 16—										
June, 1953	14.00	26.64	74.34	111.66	140.56	165.17	———	———	———	———
July, 1953	———	72.00	60.44	93.60	158.00	———	———	———	———	———
Area 14—										
July, 1954	———	———	101.00	124.56	144.23	163.38	———	———	———	———
September, 1956	———	———	92.25	133.89	151.32	167.78	195.17	———	———	———
Lower East Coast										
Area 17A—										
May, 1956	———	60.17	87.69	103.27	122.98	129.00	———	———	———	———
June, 1956	———	———	83.21	131.58	149.98	169.76	174.00	———	———	230.00
September, 1956	———	———	100.83	136.06	154.45	171.72	———	———	———	———
Area 17B—July, 1956	———	59.00	84.81	121.54	146.52	174.92	136.00	216.00	———	———
Area 18—										
June, 1956	———	59.00	93.80	120.59	137.65	160.14	190.20	185.50	———	———
July, 1956	———	34.81	93.11	126.65	147.54	166.13	172.20	———	194.00	192.00
September, 1956	———	———	91.93	122.36	152.00	———	———	———	———	———
Area 19—September, 1956	———	———	91.83	118.83	———	———	———	———	———	———
Lower West Coast										
Area 21—July, 1953	———	———	86.68	103.41	122.48	138.00	164.33	———	208.00	———

[3] No samples obtained.
[4] Salted—no weights taken.

Table VIII.—Average Sex Ratio (Females/Males) in Populations of Herring on the British Columbia Coast during the Past Five Fishing Seasons.

Population	Fishing Season				
	1952–53	1953–54	1954–55	1955–56	1956–57
Upper west coast, Queen Charlotte Islands	.....	.....	.....	.....	1.00
Lower west coast, Queen Charlotte Islands	.....	.....	.....	.....	1.91
Upper east coast, Queen Charlotte Islands	.....	1.05	1.05	1.18	1.01
Lower east coast, Queen Charlotte Islands	.....	0.48[1]	.....	1.00	1.07
Northern	0.88	1.12	1.12	1.04	1.09
Upper central	1.13	1.02	1.15	1.23	1.03
Lower central	1.37	0.96	1.16	1.15	1.02
Upper east coast	1.00	1.07	1.12	1.10	1.08
Middle east coast	1.02	1.01	1.24	1.15	0.92
Lower east coast	0.84	0.81	0.92	1.04	0.98
Lower west coast	1.06	1.07	1.07	0.93	1.97
Upper west coast	1.24	1.08	1.15	.....	1.04

[1] Based on only thirty-four fish and so omitted from averages.

Table IX.—Number of Statutory Miles of Herring Spawn, Adjusted to Medium Intensity, Deposited in British Columbia Waters and at Boundary Bay in 1957, by Area and Year.

(Comparable data are also given for the preceding four years. Figures in parentheses include surveys carried out by Biological Station personnel.)

Sub-district and Area	Statutory Miles of Spawn of Medium Intensity				
	1953	1954	1955	1956	1957
Upper Queen Charlotte Islands					
Area 2AE (Skidegate Inlet)	3.2	1.9	----	----	----
Area 2AW (Rennell Sound)	----	----	----	----	0.1
Totals	3.2	1.9	----	----	0.1
Lower Queen Charlotte Islands					
Area 2BE (Skincuttle Inlet)	10.2	20.2	11.3	9.7	2.8
Northern					
Area 3 (Nass)	0.9	0.5	----	2.6	11.1
Area 4 (Skeena)	16.1	5.4	4.3	5.8	9.8
Area 5 (Grenville)	3.3	10.5	18.8	11.9	10.8
Totals	20.3	16.4	23.1	20.3	31.7
Upper Central					
Area 6 (Butedale)	6.8	4.7	4.0	0.3	0.9
Lower Central					
Area 7 (Bella Bella)	29.4	28.0	28.2	18.8	11.4
Area 8 (Bella Coola)	0.2	2.7	8.9	1.4	1.6
Area 9 (Rivers Inlet)	4.2	0.4	1.1	0.1	0.1
Area 10 (Smith Inlet)	9.2	5.8	1.6	4.1	1.7
Totals	43.0	36.9	39.8	24.4	14.8
Upper East Coast					
Area 11 (Seymour Inlet)	----	0.4	----	----	0.1
Area 12 (Alert Bay)	24.7	14.0	9.2	15.9	9.8
Totals	24.7	14.4	9.2	15.9	9.9
Middle East Coast					
Area 13 (Campbell River)	5.8	3.2	12.2 (13.8)	---- (5.3)	2.8 (2.0)
Area 14 (Comox)	23.7	11.4	19.0 (21.0)	21.7 (22.6)	6.1
Area 15 (Powell River)	3.0	2.4	1.4 (1.6)	---- (----)	2.8 (3.2)
Area 16 (Pender Harbour)	3.2	4.8	4.0 (4.0)	2.0 (----)	1.1 (1.1)
Totals	35.7	21.8	36.6 (40.4)	23.8 (27.9)	12.8 (12.4)
Lower East Coast					
Area 17A (Nanaimo)	17.6	0.8	9.0 (9.4)	3.0 (4.2)	16.9
Area 17B (Ladysmith)	82.4	61.5	6.5 (28.8)	9.4 (7.7)	0.5
Area 18 (Ganges Harbour)	2.5	1.9	1.4 (5.2)	1.8 (9.1)	4.9
Area 19 (Victoria)	----	----	----	---- (----)	----
Totals	102.5	64.2	16.9 (43.4)	14.2 (21.0)	22.3
Lower West Coast					
Area 23 (Barkley Sound)	7.8 (13.1)	4.6 (11.0)	5.6	13.4	7.9
Area 24 (Clayoquot Sound)	7.0 (7.8)	4.2 (4.5)	4.7	1.1	1.8
Totals	14.8 (20.9)	8.8 (15.5)	10.3	14.5	9.7
Upper West Coast					
Area 25 (Esperanza Inlet)	11.4 (36.4)	7.1 (17.5)	6.9	53.2	22.0
Area 26 (Kyuquot Sound)	4.4 (8.0)	3.2 (4.8)	8.6	0.9	1.6
Area 27 (Quatsino Sound)	10.8 (11.5)	7.2 (7.3)	2.6	----	0.8
Totals	26.6 (55.9)	17.5 (29.6)	18.1	54.1	24.4
United States of America					
Boundary Bay	----	----	---- (15.6)	----	2.1 (2.1)
Grand totals, all areas	287.8 (323.2)	206.8 (225.6)	169.3 (215.2)	177.2 (188.1)	131.5 (131.1)

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1957

200-1157-3108

BRITISH COLUMBIA DEPARTMENT OF FISHERIES, 1957

Contributions to the Life-history of the Sockeye Salmon

[PAPER 42.]

BY

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[REPRINTED WITHOUT CHANGE OF PAGING FROM THE REPORT OF THE BRITISH COLUMBIA DEPARTMENT OF FISHERIES, 1956]

FRB. No. 501

APPENDICES

CONTRIBUTIONS TO THE LIFE-HISTORY OF THE SOCKEYE SALMON (No. 42)

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INTRODUCTION

This is the forty-second report in a series which was begun in 1914 by the Commissioner of Fisheries for the Province of British Columbia and has since been continued without interruption since that time, the reports appearing each year in the Report of the Commissioner of Fisheries, latterly the Report of the Provincial Department of Fisheries. The reports give, for each year, pertinent information regarding the sizes, sex ratios, and age compositions of the sockeye caught in each of the major sockeye-salmon fishing areas of the British Columbia coast, with the exception of the Fraser River, which since 1937 has been within the jurisdiction of the International Pacific Salmon Fisheries Commission. The areas dealt with, therefore, include the Nass River, Skeena River, Rivers Inlet area, and Smith Inlet area.

The samples of sockeye, from which the reported data are taken, are obtained from the commercial fishery in each area, which is, in the main, a drift gill-net fishery. To the extent, therefore, that gill-nets are selective in removing salmon from a run of fish—that is, tend to select fish of certain sizes or sex—the samples taken may not be completely typical of the whole run of fish being sampled. It has already been shown, in No. 38 of this series, that at Rivers Inlet that portion of the run that escapes the fishery and reaches the spawning-grounds (termed the "spawning escapement") may have a quite different size, sex, and age composition from that taken by the fishery.

The data herein reported pertain to the 1956 catches of sockeye. The numbers of sockeye caught in the four areas under review were taken from the statistical records of the Department of Fisheries, Vancouver. The sockeye-pack in numbers of cases given in the tables was supplied by the British Columbia Department of Recreation and Conservation, Victoria, B.C.

DESIGNATION OF AGE-GROUPS AND TREATMENT OF DATA

Two outstanding features in the life-history of the fish have been selected in designating the age-groups—namely, the age at maturity and the year of its life in which the fish migrated from fresh water. These are expressed symbolically by two numbers—one in large type, which indicates the age of maturity, and the other in small type, placed to the right and below, which signifies the year of life in which the fish left fresh water. The age-groups which are met most commonly are:—

3_1, 4_1—the "sea types" or fish which migrate seaward in their first year and mature in their third and fourth year respectively.

3_2—"the grilse," almost exclusively males and frequently called "jacks," which migrate seaward in their second year and mature in their third year.

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$4_2, 5_2$—fish which migrate seaward in their second year and mature in their fourth and fifth years respectively.

$5_3, 6_3$—fish which migrate seaward in their third year and mature in their fifth and sixth years respectively.

$6_4, 7_4$—fish which migrate seaward in their fourth year and mature in their sixth and seventh years respectively.

Fish were measured to the nearest quarter of an inch, but when averaged the average has been recorded to the nearest tenth of an inch to avoid using fractions of more than one decimal place. Weights were taken to the nearest tenth of a pound. This has resulted in an even-pound and half-pound bias when the data are grouped to the nearest quarter-pound.

1. THE NASS RIVER SOCKEYE RUN OF 1956

(1) General Characteristics

The pack of 22,505 cases of sockeye salmon (Table I) was quite good for the Nass area and above the average of 17,899 for the last ten years (1946–55).

The run in 1956 resulted from the spawning escapements of 1951 and 1952, which were reported as very satisfactory. In both these years the commercial fishery was good, packs of 24,405 and 29,492 cases respectively being made.

(2) Age-groups

The Nass River sockeye-catch sample contained 27 per cent 4-year fish, 59 per cent 5-year fish, and 14 per cent 6-year fish (Table I). Of these fish, 35.5 per cent had spent one year in fresh water, migrating seaward early in their second year; 63 per cent had spent two years in fresh water, migrating seaward early in their third year. The remainder of 1.5 per cent had migrated to sea as fry, returning as adults in their fourth year (Tables II and III).

(3) Lengths and Weights

The average weights for the main age-groups of the year's samples were slightly less than the previous ten-year average, though in most cases slightly greater than in 1955 (Tables IV and V).

(4) Distribution of Sexes

In the Nass River sockeye sample, 49.5 per cent were males and 50.5 per cent females. The percentage of males in the main age-groups was as follows: 4_2, 50 per cent; 5_2, 44 per cent; 5_3, 47 per cent, and 6_3, 61 per cent (Table VI).

2. THE SKEENA RIVER SOCKEYE RUN OF 1956

(1) General Characteristics

The effect of the Babine Rive slide, which occurred in 1951, was noted in 1955 in the small proportion of 4-year fish in the catch sample, as was expected. In the 1956 sockeye-catch sample, the expected fall-off in the 5-year fish occurred as a direct effect of the slide. The catch sample consisted mainly of 4-year fish, which came from the 1952 spawning escapement after the partial clearance of the Babine River.

The yield of 14,663 cases of sockeye in 1956 was a slight increase over the previous year's commercial catch, which represented the lowest on record from the Skeena River (Table VII).

(2) Age-groups

The 84 per cent of 4-year fish in the Skeena River sockeye-catch sample was the highest percentage of that age-group ever recorded for that area. Of the remainder, 15 per cent were 5-year fish and 1 per cent 6-year fish (Table VII).

(3) Lengths and Weights

From a consideration of Tables X and XI it can be seen that the size of the Skeena River sockeye caught in 1956, in all but the 6-year fish, was well above the average. The lengths and weights for the main age-groups were as follows: The male 4_2 fish averaged 23.6 inches and 6 pounds, and the female 4_2's, 22.9 inches and 5.3 pounds; the male 5_2 fish averaged 26.1 inches and 8.2 pounds, and the female 5_2's, 24.9 inches and 6.8 pounds; the male 5_3 fish averaged 23.9 inches and 6.6 pounds, and the female 5_3's, 23.5 inches and 6.2 pounds; the male 6_3 fish averaged 25.9 inches and 7.6 pounds, and the female 6_3's, 23.7 inches and 5.6 pounds (Tables VIII, IX, X, and XI).

(4) Distribution of Sexes

The distribution of sexes in the Skeena River sockeye-catch sample (Table XII) again shows two trends which are almost invariable. These are that the catch as a whole contains over 50 per cent females, and that the 5_2 age-group fish in the catch contains an even greater percentage of females.

3. RIVERS INLET SOCKEYE RUN OF 1956

(1) General Characteristics

The 1956 sockeye-catch, with a total of 124,634 cases, was nearly two and one-half times that of the previous year (Table XIII). In the main, the catch was resultant of the spawning escapement from the 1951 run which, itself, produced a pack well above the average. The 1951 spawning escapement, quoting from the Federal Department of Fisheries "Salmon Spawning Report, British Columbia 1951," was medium to heavy, and from this came 90 per cent of the 1956 run, according to the sample studied.

(2) Age-groups

Three age-groups were present in the 1956 catch sample: 5_2, 90 per cent, 4_2, 10 per cent; and two fish of the 5_3 age-group were noted. These proportions are quite normal for the area (Table XIII).

(3) Lengths and Weights

Lengths and weights were found to be quite normal and were well within the range recorded in previous years.

The average length for both the 4_2 male and female fish was 21.5 inches. The average length of the 5_2 male fish was 25.3 inches, and of the females, 24.3 inches (Tables XVI and XVII).

The average weights in both age-groups were slightly above the ten-year average, with the male and female 4_2 fish both at 4.7 pounds. The average weight of the 5_2 male fish was 8 pounds, and of the females, 6.9 pounds (Tables XIV and XV).

No escapement records are available this year.

(4) Distribution of Sexes

In the two age-groups, the usual relationship of a larger proportion of males amongst the 4-year-old fish sample, and a smaller proportion amongst the 5-year-old fish, again occurred (Table XVIII). The over-all proportion of male fish in the catch sample was 39 per cent.

4. THE SMITH INLET SOCKEYE RUN OF 1956

(1) General Characteristics

The yield of 36,898 cases of sockeye salmon from Smith Inlet was 30 per cent above the ten-year average of 27,725 cases. The catch sample consisted mainly of 5-year-old fish, the result of heavy supplies of sockeye reaching the spawning-grounds in 1951.

(2) Age-groups

The similarity of the Smith Inlet to the Rivers Inlet sockeye populations showed itself in the usual two main age-groups. Four per cent of the catch-sample were 4-year-old fish, and 96 per cent were 5-year-old fish (Table XIX). The three age-groups were 96 per cent 5_2 sockeye, 4 per cent 4_2 sockeye, and only one 5_3 fish was present in the sample.

(3) Lengths and Weights

The size of the Smith Inlet sockeye, as with those of Rivers Inlet, was well within the normal range over the last ten years (Tables XXII and XXIII).

The average length for the 4_2 male fish was 22.5 inches; weight, 5.6 pounds; for the female fish, 22.1 inches and 5.2 pounds. In the 5_2 age-group, the male fish averaged 24.9 inches and 7.6 pounds, and the female 5_2's, 24.3 inches and 6.9 pounds. The one male 5_3 fish in the catch sample was 22.2 inches in length and weighed 4.7 pounds (Tables XX and XXI).

(4) Sex Distribution

As in the Rivers Inlet sample, the Smith Inlet fish showed a predominance of males in the 4_2 age-group (65 per cent), while among the 5_2 age-group the females represented 62 per cent (Table XXIV). The over-all catch sample consisted only of 38 per cent male fish.

Table I.—Nass River Sockeyes, Percentages of Principal Age-groups in Runs of Successive Years and Packs

Year	Pack in Cases	Number of Sockeye[1]	Percentage of Individuals			
			4_2	5_2	5_3	6_3
1912	36,037	———	8	27	63	2
1913	23,574	———	15	12	71	2
1914	31,327	———	4	41	45	10
1915	39,349	———	19	14	59	8
1916	31,411	———	9	17	66	8
1917	22,188	———	10	15	71	4
1918	21,816	———	30	16	45	9
1919	28,259	———	7	22	65	6
1920	16,740	———	8	14	72	6
1921	9,364	———	10	7	75	8
1922	31,277	———	6	2	91	1
1923	17,821	———	11	6	77	6
1924	33,590	———	4	3	91	2
1925	18,945	———	23	8	67	2
1926	15,929	———	12	12	63	13
1927	12,026	———	8	7	81	4
1928	5,540	———	30	6	61	3
1929	16,077	———	25	9	60	6
1930	26,405	———	28	15	54	3
1931	16,929	———	10	17	67	6
1932	14,154	———	28	4	61	7
1933	9,757	———	35	7	55	3
1934	36,242	———	13	9	74	4
1935	12,712	———	11	10	73	6
1936	28,562	———	16	7	67	10
1937	17,567	———	22	4	68	6
1938	21,462	———	21	4	70	5
1939	24,357	———	14	13	66	7
1940	13,809	———	23	8	59	10
1941	24,876	———	37	7	52	4
1942	21,085	———	22	7	66	5
1943	13,412	———	5	13	67	15
1944	13,083	———	15	15	32	38
1945	9,899	———	46	11	37	6
1946	12,511	———	13	12	72	3
1947	10,849	———	15	12	56	17
1948	13,181	———	12	16	60	12
1949	9,268	———	39	6	48	7
1950	27,286	———	3	19	71	6
1951	24,405	———	41	9	31	13
1952	29,492	304,500	28	19	46	4
1953	18,163	198,400	23	22	46	9
1954	10,285	101,600	35	20	40	5
1955	13,654	154,904	12	15	70	2
1956	22,505	254,800	27	9	50	14

[1] To nearest hundred.

Table II.—Nass River Sockeyes, 1956, Grouped by Age, Sex, Length, and by Their Early History

Length in Inches	Number of Individuals												Total
	4_1		4_2		4_3		5_2		5_3		6_3		
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	
18¾	1												1
19													
19¼					1								1
19½													
19¾			1	1									2
20	1												1
20¼													
20½			2	1					1		1		5
20¾													
21				5						2			7
21¼		1		3				1	1	2			8
21½			3	8					2	2			15
21¾				4					1	3			8
22			3	8					1	7			19
22¼		1	4	14					2	10			31
22½		1	13	34	1			1	11	29			90
22¾		1	7	10					4	13	1		36
23		2	15	11				2	6	22	1		59
23¼			8	6					10	22		1	47
23½		3	7	15			1	8	25	34			93
23¾			31	4			1	3	19	23	1		82
24			10	2				2	22	15	3	3	57
24¼			10	2			1	6	19	17		3	58
24½			13	2			2	7	32	23	1	6	86
24¾			4	1			3	3	17	13	4	6	51
25	1		1				2	9	16	7	1	4	41
25¼	2		2				3	2	9	7	4	4	33
25½				1			7	2	13	7	5	5	40
25¾							4	2	9	3	1	4	23
26			1	1			3	1	7	1	4	2	20
26¼			2				4		6	1	8	2	23
26½			1	1			2		3	5	11	3	26
26¾				1			1				5	4	12
27				1			3				6	2	12
27¼							1	1			9	1	12
27½							1				3		4
27¾											1	2	3
28											4		4
28¼									1		7		8
28½										1	1		2
28¾											1		1
Totals	5	9	138	136	2		39	50	238	269	83	52	1,021
Average lengths	22.8	22.8	23.5	22.8	20.9		25.6	24.4	24.3	23.6	26.4	25.4	24.0

Table III.—Nass River Sockeyes, 1956, Grouped by Age, Sex, Weight, and by Their Early History

Weight in Pounds	Number of Individuals												Total
	4_1		4_2		4_3		5_2		5_3		6_3		
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	
3					1								1
3¼	1												1
3½	1		2	2									5
3¾				3									3
4				1						3			4
4¼			2	6					2	5			15
4½		1	3	28					1	13			46
4¾			5	14					2	17			38
5		2	11	17					5	29			64
5¼			7	25	1			4	6	30		1	74
5½		4	23	28				4	33	50	1	1	144
5¾		1	21	3				5	20	27	1	2	80
6			26	2				4	22	25		3	82
6¼		1	13	2			1	4	21	20	3	6	71
6½	1		15	5			5	10	44	26	4	8	118
6¾	1		3					4	17	6	3	6	40
7			4				4	6	12	3	4	2	35
7¼			1				3	1	18	6	2	7	38
7½	1		2				12	6	17	6	11	7	62
7¾							2	2	6	2	3	1	16
8							2		6		5	3	16
8¼							1		2		9		12
8½							5		1	1	14	2	23
8¾							2		1		6	3	12
9							1				3		4
9¼											2		2
9½									1		6		7
9¾							1		1		2		4
10											2		2
10¼											2		2
Totals	5	9	138	136	2		39	50	238	269	83	52	1,021
Average weights	5.5	5.4	5.8	5.0	4.1		7.6	6.4	6.4	5.7	8.1	7	6.1

Table IV.—Nass River Sockeyes, Average Lengths in Inches of Principal Age-groups, 1912 to 1956

Year	4_2		5_2		5_3		6_3	
	M.	F.	M.	F.	M.	F.	M.	F.
1912–41	24.5	23.7	26.3	25.2	26.1	25.3	27.7	26.4
1912–41 (conversion)	23.8	23.0	25.6	24.5	25.4	24.6	27.0	25.7
1942	23.9	23.2	26.1	24.9	24.9	24.3	26.9	26.0
1943	22.8	22.2	26.1	24.8	24.1	23.5	27.1	25.8
1944	23.5	22.7	25.7	24.6	24.8	23.8	26.8	25.8
1945	23.4	22.8	25.0	24.4	24.7	24.0	25.1	25.5
1946	23.4	22.4	26.3	24.9	24.9	23.9	28.1	26.0
1947	23.4	22.9	25.9	24.1	24.5	23.6	27.0	25.6
1948	23.3	22.6	26.2	25.3	25.0	24.1	27.7	26.7
1949	23.8	22.8	26.2	23.8	24.7	23.7	26.1	25.5
1950	23.6	23.1	26.0	24.7	24.5	23.7	26.7	25.6
1951	24.0	23.1	26.2	24.8	25.1	24.1	27.4	26.4
1952	23.9	23.1	26.8	25.3	24.8	23.9	27.6	26.3
1953	23.9	22.9	26.9	25.6	24.9	24.1	27.7	26.5
1954	24.1	23.1	26.5	25.3	25.3	24.5	27.7	26.0
1955	23.1	22.3	26.0	24.7	24.1	23.2	26.9	25.1
1956	23.5	22.8	25.6	24.4	24.3	23.6	26.4	25.4

Table V.—Nass River Sockeyes, Average Weights in Pounds of Principal Age-groups, 1914 to 1956

Year	4_2		5_2		5_3		6_3	
	M.	F.	M.	F.	M.	F.	M.	F.
1914–41	6.0	5.4	7.3	6.4	6.9	6.2	8.0	7.0
1942	5.8	5.1	7.1	6.3	6.2	5.6	7.5	6.7
1943	5.2	4.7	7.6	6.4	5.9	5.3	7.9	6.9
1944	5.7	5.0	7.7	6.5	6.7	5.7	8.2	7.1
1945	5.7	5.3	7.0	6.4	6.5	5.9	7.2	7.1
1946	5.6	4.9	8.1	6.7	6.5	5.4	8.9	7.0
1947	5.8	5.3	7.7	6.2	6.3	5.6	8.1	6.9
1948	5.8	5.3	8.1	7.1	7.0	6.0	9.1	7.9
1949	5.9	5.1	7.9	5.8	6.5	5.4	7.7	6.8
1950	5.9	5.2	7.9	6.6	6.4	5.5	8.2	7.1
1951	6.0	5.2	7.9	6.6	6.7	5.7	8.8	7.6
1952	6.0	5.2	8.4	6.9	6.7	5.7	8.7	7.5
1953	6.2	5.4	8.3	7.2	6.6	5.8	9.0	7.9
1954	6.4	5.5	8.8	7.4	7.4	6.3	9.5	7.8
1955	5.6	4.9	7.8	6.8	6.1	5.4	8.3	6.9
1956	5.8	5.0	7.5	6.4	6.4	5.7	8.1	7.0

Table VI.—Nass River Sockeyes, Percentages of Males and Females, 1915 to 1956

Year	4_2		5_2		5_3		6_3		Per Cent Total Males	Per Cent Total Females
	M.	F.	M.	F.	M.	F.	M.	F.		
1915–41 (average)	49	51	47	53	45	55	63	37	47	53
1942	42	58	48	52	44	56	70	30	45	55
1943	51	49	67	33	47	53	74	26	54	46
1944	53	47	45	55	39	61	60	40	50	50
1945	37	63	37	63	38	62	53	47	38	62
1946	62	38	59	41	45	55	75	25	50	50
1947	50	50	52	48	51	49	81	19	56	44
1948	45	55	54	46	52	48	66	34	53	47
1949	57	43	56	44	51	49	50	50	53	47
1950	41	59	42	58	43	57	58	42	44	56
1951	46	54	47	53	46	54	70	30	49	51
1952	49	51	56	44	49	51	59	41	50	50
1953	50	50	44	56	46	54	62	38	48	52
1954	42	58	44	56	44	56	45	55	43	57
1955	50	50	60	40	47	53	68	32	49	51
1956	50	50	44	56	47	53	61	39	50	50

Table VII.—Skeena River Sockeyes, Percentages of Age-groups in Runs of Successive Years and Packs

Year	Pack in Cases	Number of Sockeye[1]	Percentage of Individuals			
			4_2	5_2	5_3	6_3
1907	108,413	———	—	—	—	—
1908	139,846	———	—	—	—	—
1909	87,901	———	—	—	—	—
1910	187,246	———	—	—	—	—
1911	131,066	———	—	—	—	—
1912	92,498	———	57	43	—	—
1913	52,927	———	50	50	—	—
1914	130,166	———	25	75	—	—
1915	116,553	———	36	64	—	—
1916	60,923	———	34	38	13	18
1917	65,760	———	57	29	9	5
1918	123,322	———	51	34	9	6
1919	184,945	———	27	60	9	4
1920	90,869	———	15	71	6	8
1921	41,018	———	69	22	6	3
1922	96,277	———	70	16	12	2
1923	131,731	———	56	29	8	7
1924	144,747	———	23	69	7	1
1925	77,784	———	51	45	3	1
1926	82,360	———	62	26	9	3
1927	83,996	———	62	28	9	1
1928	34,559	———	51	39	7	3
1929	78,017	———	62	30	6	2
1930	132,372	———	39	52	8	1
1931	93,023	———	40	30	28	2
1932	59,916	———	44	37	7	12
1933	30,506	———	57	36	5	2
1934	54,558	———	58	34	7	1
1935	52,879	———	49	31	18	2
1936	81,973	———	67	20	11	2
1937	42,491	———	45	40	11	4
1938	47,257	———	64	15	16	5
1939	68,485	———	50	35	11	4
1940	116,507	———	80	15	4	1
1941	81,767	———	39	52	8	1
1942	34,544	———	36	54	7	3
1943	28,268	———	39	39	16	6
1944	68,197	———	37	52	7	4
1945	104,279	———	20	63	12	5
1946	52,928	———	13	70	8	9
1947	32,534	———	14	82	3	1
1948	101,267	———	80	13	6	1
1949	65,937	———	17	76	4	3
1950	47,479	———	21	72	4	3
1951	61,694	———	33	61	4	1
1952	114,775	1,294,500	66	26	3	5
1953	65,003	659,200	48	43	6	3
1954	60,817	571,900	33	54	10	2
1955	14,649	157,362	15	59	14	11
1956	14,663	149,100	84	14	1	1

[1] To nearest hundred.

Table VIII.—Skeena River Sockeyes, 1956, Grouped by Age, Sex, Length, and by Their Early History

Length in Inches	Number of Individuals								Total
	4_2		5_2		5_3		6_3		
	M.	F.	M.	F.	M.	F.	M.	F.	
19¾	—	1	—	—	—	—	—	—	1
20	1	1	—	—	—	—	—	—	2
20¼	2	1	—	—	—	—	—	—	3
20½	2	—	—	—	—	—	—	—	2
20¾	2	3	—	—	—	—	—	—	5
21	—	—	—	—	—	—	—	—	—
21¼	5	10	—	—	—	—	—	—	15
21½	3	6	—	—	—	—	—	—	9
21¾	2	11	—	—	—	—	—	—	13
22	5	18	—	—	—	—	—	—	23
22¼	4	15	—	—	—	—	—	—	19
22½	6	16	—	—	1	—	—	—	23
22¾	8	18	—	1	—	—	—	—	27
23	24	38	—	—	—	—	—	1	63
23¼	16	16	—	—	—	—	—	1	33
23½	13	13	—	2	—	1	—	1	30
23¾	17	11	—	2	1	—	—	—	31
24	41	17	1	6	—	—	—	—	65
24¼	26	5	1	2	—	—	—	1	35
24½	15	1	—	2	—	—	—	—	18
24¾	25	3	—	12	—	—	—	1	41
25	4	—	—	2	—	—	—	—	6
25¼	3	—	—	4	—	—	—	—	7
25½	2	1	4	9	1	—	1	—	18
25¾	—	—	1	—	—	—	—	—	1
26	2	—	5	5	—	—	—	—	12
26¼	—	1	2	1	—	—	1	—	5
26½	—	1	4	2	—	—	—	—	7
26¾	2	—	—	—	—	—	—	—	2
27	—	—	1	—	—	—	—	—	1
27¼	—	—	—	—	—	—	—	—	—
27½	—	—	1	—	—	—	—	—	1
27¾	—	—	1	—	—	—	—	—	1
28	—	—	1	—	—	—	—	—	1
Totals	230	207	22	50	3	1	2	5	520
Average lengths	23.6	22.9	26.1	24.9	23.9	23.5	25.9	23.7	23.5

Table IX.—Skeena River Sockeyes, 1956, Grouped by Age, Sex, Weight, and by Their Early History

Weight in Pounds	Number of Individuals								Total
	4_2		5_2		5_3		6_3		
	M.	F.	M.	F.	M.	F.	M.	F.	
3	—	1	—	—	—	—	—	—	1
3¼	—	—	—	—	—	—	—	—	—
3½	5	1	—	—	—	—	—	—	6
3¾	2	4	—	—	—	—	—	—	6
4	4	6	—	—	—	—	—	—	10
4¼	—	8	—	—	—	—	—	—	8
4½	13	25	—	—	—	—	—	—	38
4¾	5	22	—	—	—	—	—	1	28
5	6	13	—	—	—	—	—	2	21
5¼	5	21	—	—	1	—	—	—	27
5½	31	50	—	2	—	—	—	—	83
5¾	17	14	—	2	—	—	—	—	33
6	20	22	—	5	—	—	—	1	48
6¼	23	5	—	7	—	1	—	—	36
6½	48	14	1	5	1	—	—	—	69
6¾	11	—	—	5	—	—	—	—	16
7	8	—	3	5	—	—	—	—	16
7¼	11	—	1	8	—	—	—	1	21
7½	8	1	1	5	—	—	1	—	16
7¾	9	—	1	4	—	—	—	—	14
8	1	—	4	—	1	—	1	—	7
8¼	1	—	5	—	—	—	—	—	6
8½	1	—	1	2	—	—	—	—	4
8¾	1	—	—	—	—	—	—	—	1
9	—	—	2	—	—	—	—	—	2
9¼	—	—	1	—	—	—	—	—	1
9½	—	—	—	—	—	—	—	—	—
9¾	—	—	—	—	—	—	—	—	—
10	—	—	—	—	—	—	—	—	—
10¼	—	—	1	—	—	—	—	—	1
10½	—	—	1	—	—	—	—	—	1
Totals	230	207	22	50	3	1	2	5	520
Average weights	6.0	5.3	8.2	6.8	6.6	6.2	7.6	5.6	5.9

Table X.—Skeena River Sockeyes, Average Lengths in Inches of Principal Age-groups, 1912 to 1956

Year	4_2		5_2		5_3		6_3	
	M.	F.	M.	F.	M.	F.	M.	F.
1912–41	23.7	23.1	25.8	24.9	24.2	23.4	25.8	24.8
1912–41 (conversion)	23.0	22.4	25.1	24.2	23.5	22.7	25.1	24.1
1942	22.6	22.3	25.2	24.3	24.1	23.7	26.3	24.9
1943	21.9	21.9	25.1	23.9	23.3	22.6	25.8	24.7
1944	22.4	21.7	24.8	23.9	22.5	21.7	25.0	23.7
1945	22.6	22.3	24.9	24.1	23.3	22.6	25.0	24.3
1946	22.7	22.0	25.4	24.3	23.9	23.2	25.5	24.4
1947	22.3	22.0	25.1	23.8	23.0	22.4	26.3	25.8
1948	23.0	22.3	25.3	24.1	23.0	22.1	26.0	24.5
1949	22.5	22.2	25.3	24.5	23.2	22.3	24.8	23.9
1950	22.8	22.3	25.7	24.4	23.9	23.4	25.5	24.3
1951	22.7	22.6	25.9	24.8	23.6	22.9	26.0	24.6
1952	23.3	22.6	25.8	24.7	23.2	22.8	26.1	24.6
1953	23.2	22.8	26.2	25.0	23.6	22.9	26.0	25.5
1954	22.2	22.4	26.6	25.2	23.9	22.9	26.4	24.9
1955	22.5	22.1	**25.6**	**24.5**	23.0	**22.6**	**25.2**	**24.0**
1956	23.6	22.9	26.1	24.9	23.9	23.5	25.9	23.7

Table XI.—Skeena River Sockeyes, Average Weights in Pounds of Principal Age-groups, 1914 to 1956

Year	4_2		5_2		5_3		6_3	
	M.	F.	M.	F.	M.	F.	M.	F.
1914–41	5.4	5.0	6.8	6.1	5.7	5.1	6.8	6.0
1942	4.9	4.7	6.7	6.0	5.8	5.4	7.2	6.6
1943	4.7	4.6	6.8	5.9	5.5	4.9	7.3	6.1
1944	5.1	4.6	7.0	6.1	5.3	4.6	7.1	5.8
1945	5.2	4.9	6.7	6.1	5.6	5.0	6.7	6.2
1946	4.7	4.2	6.9	5.8	5.8	5.1	7.0	6.1
1947	4.9	4.7	6.9	5.9	5.3	5.0	7.7	6.8
1948	5.5	4.9	7.3	6.1	5.4	4.7	7.7	6.4
1949	5.0	4.7	7.1	6.3	5.3	4.8	6.6	5.7
1950	4.8	4.3	7.2	5.9	5.8	5.1	6.8	5.6
1951	5.1	5.0	7.6	6.5	5.6	5.0	7.6	6.4
1952	5.6	5.0	7.5	6.4	5.6	5.0	7.4	6.0
1953	5.8	5.5	8.0	6.9	5.8	5.2	7.8	7.3
1954	4.9	4.9	8.8	7.2	6.2	5.2	8.6	7.2
1955	4.9	4.8	7.4	6.4	5.5	5.0	7.1	6.1
1956	6.0	5.3	8.2	6.8	6.6	6.2	7.6	5.6

Table XII.—Skeena River Sockeyes, Percentages of Males and Females, 1915 to 1956

Year	4_2		5_2		Per Cent Total Males	Per Cent Total Females
	M.	F.	M.	F.		
1915–41 (average)	48	52	43	57	46	54
1942	42	58	25	75	33	67
1943	50	50	31	69	43	57
1944	54	46	34	66	43	57
1945	41	59	35	65	38	62
1946	50	50	32	68	38	62
1947	50	50	29	71	33	67
1948	50	50	29	71	47	53
1949	54	46	30	70	36	64
1950	56	44	40	60	44	56
1951	41	59	37	63	39	61
1952	52	48	34	66	48	52
1953	40	60	34	66	39	61
1954	44	56	38	62	43	57
1955	57	43	42	58	47	53
1956	53	47	34	66	44	56

Table XIII.—Rivers Inlet Sockeyes, Percentages of Age-groups in Runs of Successive Years and Packs

Year	Pack in Cases	Number of Sockeye[1]	Percentage of Individuals			
			4_2	5_2	5_3	6_3
1907	87,874	———	—	—	—	—
1908	64,652	———	—	—	—	—
1909	89,027	———	—	—	—	—
1910	126,921	———	—	—	—	—
1911	88,763	———	—	—	—	—
1912	112,884	———	21	79	—	—
1913	61,745	———	80	20	—	—
1914	89,890	———	35	65	—	—
1915	130,350	———	13	87	—	—
1916	44,936	———	26	74	—	—
1917	61,195	———	39	61	—	—
1918	53,401	———	57	43	—	—
1919	56,258	———	46	54	—	—
1920	121,254	———	5	95	—	—
1921	46,300	———	49	51	—	—
1922	60,700	———	81	18	1	—
1923	107,174	———	74	24	2	—
1924	94,891	———	43	54	2	1
1925	159,554	———	23	77	—	—
1926	65,581	———	59	38	2	1
1927	64,461	———	81	16	3	—
1928	60,044	———	55	40	4	1
1929	70,260	———	77	18	3	2
1930	119,170	———	49	48	2	1
1931	76,428	———	53	44	2	1
1932	69,732	———	67	27	5	1
1933	83,507	———	44	55	1	—
1934	76,923	———	77	20	2	1
1935	135,038	———	57	41	1	1
1936	46,351	———	53	46	1	—
1937	84,832	———	60	37	3	—
1938	87,942	———	27	70	1	2
1939	54,143	———	67	32	1	—
1940	63,469	———	69	28	3	—
1941	93,378	———	59	40	1	—
1942	79,199	———	8	91	—	1
1943	47,602	———	8	91	—	1
1944	36,852	———	76	23	1	—
1945	89,735	———	57	41	2	—
1946	73,320	———	37	63	—	—
1947	140,087	———	3	97	—	—
1948	37,665	———	55	44	1	—
1949	39,495	———	84	14	1	—
1950	142,710	———	13	87	(2)	—
1951	102,565	———	38	60	1	1
1952	84,298	938,700	41	58	1	(2)
1953	132,925	1,522,300	73	26	1	(2)
1954	50,640	575,700	60	39	1	(2)
1955	50,702	584,128	45	54	(2)	1
1956	124,634	1,072,300	10	90	(2)	—

[1] To nearest hundred.
[2] Age-class represented but less than 0.5 per cent.

Table XIV.—Rivers Inlet Sockeyes, 1956, Grouped by Age, Sex, Length, and by Their Early History

Length in Inches	Number of Individuals						Total
	4_2		5_2		5_3		
	M.	F.	M.	F.	M.	F.	
19¼	1	1	—	1	—	—	3
19½	2	2	—	—	—	—	4
19¾	2	—	—	—	—	—	2
20	5	4	—	—	—	—	9
20¼	8	2	2	—	—	—	12
20½	7	2	—	—	—	—	9
20¾	3	2	—	—	—	—	5
21	2	6	1	1	—	—	10
21¼	4	3	1	3	—	—	11
21½	5	4	3	2	—	—	14
21¾	5	3	2	7	—	—	17
22	5	3	6	14	—	1	29
22¼	1	3	3	15	—	—	22
22½	4	3	3	20	—	—	30
22¾	1	2	4	14	—	—	21
23	4	3	5	27	—	—	39
23¼	—	—	7	22	1	—	30
23½	3	1	7	41	—	—	52
23¾	2	2	14	36	—	—	54
24	2	1	7	55	—	—	65
24¼	2	—	11	49	—	—	62
24½	—	—	16	71	—	—	87
24¾	—	—	15	51	—	—	66
25	—	—	23	76	—	—	99
25¼	—	—	20	49	—	—	69
25½	—	—	45	42	—	—	87
25¾	—	—	27	20	—	—	47
26	—	—	43	20	—	—	63
26¼	—	—	23	10	—	—	33
26½	—	—	38	3	—	—	41
26¾	—	—	14	—	—	—	14
27	—	—	14	—	—	—	14
27¼	—	—	5	—	—	—	5
27½	—	—	6	—	—	—	6
27¾	—	—	2	—	—	—	2
Totals	68	47	367	649	1	1	1,133
Average lengths	21.5	21.5	25.3	24.3	23.2	22	24.3

Table XV.—Rivers Inlet Sockeyes, 1956, Grouped by Age, Sex, Weight, and by Their Early History

Weight in Pounds	Number of Individuals						Total
	4_2		5_2		5_3		
	M.	F.	M.	F.	M.	F.	
3¼	—	1	—	—	—	—	1
3½	6	4	—	—	—	—	10
3¾	7	3	—	1	—	—	11
4	8	6	2	1	—	—	17
4¼	9	3	2	4	—	—	18
4½	6	7	1	6	—	—	20
4¾	6	—	4	11	—	1	22
5	3	7	7	19	—	—	36
5¼	2	4	1	20	—	—	37
5½	8	5	10	40	—	—	53
5¾	4	2	4	33	—	—	43
6	4	3	14	39	1	—	61
6¼	1	—	7	30	—	—	38
6½	2	2	12	61	—	—	77
6¾	—	—	8	33	—	—	41
7	1	—	15	73	—	—	89
7¼	1	—	12	46	—	—	59
7½	—	—	11	55	—	—	66
7¾	—	—	25	37	—	—	62
8	—	—	34	60	—	—	94
8¼	—	—	17	23	—	—	40
8½	—	—	48	24	—	—	72
8¾	—	—	25	14	—	—	39
9	—	—	28	13	—	—	41
9¼	—	—	24	1	—	—	25
9½	—	—	20	4	—	—	24
9¾	—	—	16	—	—	—	16
10	—	—	7	1	—	—	8
10¼	—	—	9	—	—	—	9
10½	—	—	2	—	—	—	2
10¾	—	—	—	—	—	—	—
11	—	—	2	—	—	—	2
Totals	68	47	367	649	1	1	1,133
Average weights	4.7	4.7	8.0	6.9	6	4.7	7.0

Table XVI.—Rivers Inlet Sockeyes, Average Lengths in Inches of the 4_2 and 5_2 Groups, 1912 to 1956

Year	4_2		5_2	
	M.	F.	M.	F.
1912–41	22.4	22.4	25.4	24.7
1912–41 (conversion)	21.6	21.6	24.6	23.9
1942	21.9	21.3	25.0	23.8
1943	20.5	21.1	24.3	23.7
1944	21.1	21.0	23.5	23.3
1945	20.9	21.2	24.2	23.9
1946	20.6	21.1	25.1	24.1
1947	20.6	20.7	24.0	23.5
1948	21.4	21.3	25.2	24.2
1949	20.9	21.4	23.8	22.8
1950	21.1	20.8	25.2	24.2
1951	21.9	21.9	25.8	24.8
1952	21.5	21.5	26.0	25.0
1953	21.6	21.8	26.5	25.3
1954	22.0	21.6	26.1	25.1
1955	21.2	21.0	25.4	24.5
1956	21.5	21.5	25.3	24.3

Table XVII.—Rivers Inlet Sockeyes, Average Weights in Pounds of the 4_2 and 5_2 Groups, 1914 to 1956

Year	4_2		5_2	
	M.	F.	M.	F.
1914–41	4.9	4.8	7.0	6.5
1942	5.1	4.6	7.2	6.4
1943	4.1	4.4	6.8	6.3
1944	4.6	4.4	6.2	6.0
1945	4.3	4.4	6.6	6.4
1946	3.9	3.9	7.2	6.2
1947	4.1	3.9	6.4	5.9
1948	4.7	4.6	7.9	7.0
1949	4.4	4.3	5.9	5.9
1950	4.2	3.9	7.5	6.4
1951	5.2	5.0	8.6	7.4
1952	4.9	4.7	8.7	7.4
1953	4.7	4.7	8.8	7.6
1954	5.2	4.8	8.9	7.6
1955	4.5	4.2	7.4	6.5
1956	4.7	4.7	8.0	6.9

Table XVIII.—Rivers Inlet Sockeyes, Percentages of Males and Females, 1915 to 1956

Year	4_1		4_2		5_2		Per Cent Total Males	Per Cent Total Females
	M.	F.	M.	F.	M.	F.		
1915–41 (average)	—	—	63	37	34	66	50	50
1942	—	—	61	39	35	65	38	62
1943	—	—	62	38	34	66	36	64
1944	—	—	67	33	33	67	59	41
1945	—	—	70	30	39	61	57	43
1946	—	—	79	21	37	63	53	47
1947	—	—	72	28	35	65	36	64
1948	—	—	50	50	38	62	45	55
1949	36	64	70	30	22	78	63	37
1950	50	50	75	25	36	64	41	59
1951	—	—	66	34	30	70	44	56
1952	—	—	58	42	34	66	44	56
1953	—	—	55	45	33	67	49	51
1954	50	50	67	33	29	71	52	48
1955	—	—	67	33	31	69	48	52
1956	—	—	59	41	36	64	39	61

Table XIX.—Smith Inlet Sockeyes, Percentages of Age-groups in Runs of Successive Years and Packs

Year	Pack in Cases	Number of Sockeye[1]	Percentage of Individuals				
			4_1	4_2	5_2	6_2	5_3
1925	33,764						
1926	17,921						
1927	22,682						
1928	33,442						
1929	9,683						
1930	32,057						
1931	12,867						
1932	25,488						
1933	37,369						
1934	14,607						
1935	31,648						
1936	12,788						
1937	25,258						
1938	33,894						
1939	17,833						
1940	25,947						
1941	21,495						
1942	15,939						
1943	15,010						
1944	3,165						
1945	15,014			50	50		
1946	14,318			11	89		
1947	36,800			5	95		
1948	10,456			7	90	3	
1949	13,189		2	92	5		(2)
1950	42,435			17	83		(2)
1951	49,473			22	77	(2)	(2)
1952	34,834	342,200		8	91	(2)	1
1953	29,947	367,100		89	10	1	(2)
1954	18,937	190,800	1	61	38		1
1955	28,864	325,478		42	58		(2)
1956	36,898	442,300		4	96	(2)	

[1] To nearest hundred.
[2] This age-class was represented by less than 0.5 per cent of the number of fish in the sample.

Table XX.—Smith Inlet Sockeyes, 1956, Grouped by Age, Sex, Length, and by Their Early History

Length in Inches	Number of Individuals						Total
	4_2		5_2		5_3		
	M.	F.	M.	F.	M.	F.	
20¼	1						1
20½							
20¾		1					1
21		1					1
21¼	1						1
21½	1			1			2
21¾		2	1				3
22	4	2	3	1			10
22¼	4	1	1	1	1		8
22½	4	1	1	4			10
22¾	2	2	1	12			17
23	1	1	3	19			24
23¼			5	31			36
23½		1	9	37			47
23¾			13	63			76
24			19	81			100
24¼	3		26	68			97
24½	1		40	78			119
24¾			34	66			100
25			46	56			102
25¼			39	38			77
25½			46	24			70
25¾			30	13			43
26			15	7			22
26¼			9	2			11
26½			10				10
26¾			6				6
27			1				1
27¼			1				1
27½			1				1
Totals	22	12	360	602	1		997
Average lengths	22.5	22.1	24.9	24.3	22.2		24.5

Table XXI.—Smith Inlet Sockeyes, 1956, Grouped by Age, Sex, Weight, and by Their Early History

Weight in Pounds	Number of Individuals						Total
	4_2		5_2		5_3		
	M.	F.	M.	F.	M.	F.	
4		1					1
4¼	1						1
4½	1	2					3
4¾	2			2	1		5
5	4	2	3	1			10
5¼		3	1	6			10
5½	6	1	7	22			36
5¾	3	1	3	24			31
6		2	6	28			36
6¼			9	33			42
6½	2		25	117			144
6¾	1		18	59			78
7			14	72			86
7¼	1		38	61			100
7½	1		63	87			151
7¾			25	30			55
8			37	15			52
8¼			34	19			53
8½			36	17			53
8¾			9	5			14
9			8	3			11
9¼			8				8
9½			7	1			8
9¾			4				4
10			2				2
10¼							
10½			3				3
Totals	22	12	360	602	1		997
Average weights	5.6	5.2	7.6	6.9	4.7		7.1

Table XXII.—Smith Inlet Sockeyes, Average Lengths in Inches of Age-groups, 1945 to 1956

Year	4_1		4_2		5_2		6_2		5_3	
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.
1945			22.2	22.0	25.1	24.4				
1946			21.3	22.7	24.7	24.0				
1947			23.2	23.4	25.2	24.3				
1948			21.9	21.7	25.0	24.3	26.7	25.0		
1949	25.4	23.5	21.4	21.7	24.6	24.3		25.5		
1950			21.6	21.7	24.8	24.0			20.5	
1951			22.8	22.0	25.6	24.8		25.1	23.4	
1952			21.8	22.4	25.7	24.9		25.1	22.9	23.1
1953		24.3	22.9	22.3	25.9	25.2			22.8	23.3
1954	26.3	25.0	22.3	21.9	25.7	24.9			23.0	23.5
1955			21.8	21.6	25.3	24.6				22.3
1956			22.5	22.1	24.9	24.3			22.2	

Table XXIII.—Smith Inlet Sockeyes, Average Weights in Pounds of Age-groups, 1945 to 1956

Year	4_1		4_2		5_2		6_2		5_3	
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.
1945	—	—	4.9	4.7	7.1	6.5	—	—	—	—
1946	—	—	4.6	5.8	7.3	6.6	—	—	—	—
1947	—	—	5.7	5.5	6.9	6.0	—	—	—	—
1948	—	—	5.1	5.4	7.6	6.9	10.3	7.5	—	—
1949	7.9	6.1	5.0	5.1	7.2	6.7	—	7.3	—	—
1950	—	—	4.9	5.0	7.4	6.6	—	—	4.0	—
1951	—	—	6.0	5.2	8.2	7.3	—	7.2	6.4	—
1952	—	—	4.8	5.2	8.0	7.1	—	7.3	5.7	5.4
1953	—	5.9	5.9	5.3	8.2	7.6	—	—	5.7	5.8
1954	8.0	7.1	5.2	4.7	7.9	7.0	—	—	5.8	5.8
1955	—	—	5.0	4.7	7.5	6.9	—	—	—	4.8
1956	—	—	5.6	5.2	7.6	6.9	—	—	4.7	—

Table XXIV.—Smith Inlet Sockeyes, Percentages of Males and Females, 1945 to 1956

Year	4_1		4_2		5_2		6_2		5_3		Per Cent Total Males	Per Cent Total Females
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.		
1945	—	—	73	27	49	51	—	—	—	—	61	39
1946	—	—	76	24	37	63	—	—	—	—	41	59
1947	—	—	38	62	47	53	—	—	—	—	46	54
1948	—	—	79	21	42	58	11	89	—	—	43	57
1949	36	64	80	20	40	60	—	100	—	—	77	23
1950	—	—	86	14	42	58	—	—	100	—	49	51
1951	—	—	72	28	41	59	—	100	100	—	48	52
1952	—	—	57	43	38	62	—	100	63	37	40	60
1953	—	100	60	40	36	64	—	—	71	29	58	42
1954	25	75	70	30	25	75	—	—	25	75	52	48
1955	—	—	76	24	37	63	—	—	—	100	54	46
1956	—	—	65	35	38	62	—	—	100	—	38	62

Printed by Don McDiarmid, Printer to the Queen's Most Excellent Majesty
in right of the Province of British Columbia.
1957

1,200-1157-3108

THE DETERMINANTS OF PRODUCTION IN NORTHERN SEAS: A STUDY OF THE BIOLOGY OF THEMISTO LIBELLULA MANDT.

"CALANUS" SERIES NO. 14[1]

M. J. Dunbar

Abstract

The level of production in the sea is determined not only by the extrinsic factors of the environment, but also by the intrinsic response of the organism to those factors, temperature in particular. In cold seas, the degree of adaptation to low temperature as regards activity, metabolism, growth rate, and the onset of maturity is therefore of great importance. This matter is reviewed and discussed here, and illustrated by a study of the growth rate, breeding cycle, and longevity of a dominant arctic pelagic amphipod, *Themisto libellula* Mandt.

Themisto libellula, in Hudson Bay, Hudson Strait, and the waters of southeast Baffin Island, is shown to have a normal length of life of 2 years, although a 1-year or 15-month life cycle is a possibility in a small proportion of the population. Material from the months of November and December is lacking, but it appears that spawning extends from September through the winter until some time in May or June. If a temperature stimulus is involved in the onset of breeding, it appears to be a fall below, not a rise above, a critical point, since the temperatures during most of the breeding period are below −1.5° C. The spawning in the autumn, however, suggests that temperature is in fact not involved.

The alternating, or two-phase, breeding cycle is confirmed in this species, but the evidence shows that dislocations in the cycle (owing to the possibility of maturation after approximately one year in some individuals) may destroy the supposed reproductive isolation between adjacent year-classes.

Introduction

This paper is a contribution to the study of production in northern waters, production being described in terms of (1) the rate at which organic stuff is made in the seasonal cycle, and (2) the size and density of the resultant standing crop at the height of the seasonal cycle. These, in different trophic levels, depend on a variety of factors, some of them probably still unknown. There is no reason to assume that diatoms, dinoflagellates, zooplankton, fishes, in fact all the poikilothermal elements in the biomass, should be influenced in the same way by the determining environmental factors, or that the production at each level is used to the full by the level above. A large and fast production of phytoplankton, for instance, will make possible a large production of planktonic Crustacea, but it does not follow that the crustacean production will in fact be large, or that it will use the phytoplankton production to the greatest degree possible. There is normally a considerable wastage of plant food by the animals when the former is in great abundance, and a greater or smaller proportion of the plant food will always die unconsumed. The element of wastage was recognized by Volterra (1928 (44)), amongst others, who introduced into his equation for the growth rate of

[1] Manuscript received August 15, 1957.

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predator populations a coefficient of food utilization, and Riley (1953 (32)) describes the faecal pellets of zooplankton as being green with discarded and unused plant material following the phytoplankton bloom.

In *terrestrial* polar and mountain environments there is another element which apparently operates so that the maximum possible density of wildlife population is seldom if ever reached, namely the constant or intermittent adverse effects of the climate (Wynne-Edwards, 1952 (47)). In describing the redpoll population in the region of Clyde River, eastern Baffin Island, Wynne-Edwards writes: "Except perhaps among carnivorous predators, competition between individuals for space and nourishment seems commonly to be reduced to a low level among members of the arctic flora and fauna; they live somewhat like weeds, the secret of whose success lies in their ability to exploit transient conditions while they last, in the absence of serious competition. In the arctic the struggle for existence is overwhelmingly against the physical world, now sufficiently benign, now below the threshold for successful reproduction, and now so violent that life is swept away, after which recolonization alone can restore it". This factor, if it applies at all in marine environments, might be expected to take effect only in transition areas between the main zones (arctic, subarctic, boreal), where sudden changes in marine climate might have drastic and possibly differential consequences on parts of the system.

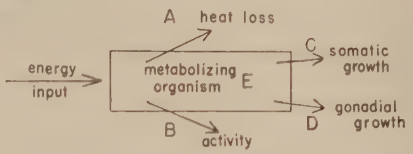


FIG. 1. See text.

Apart from this strictly extrinsic factor, the extent to which the basic (plant) production is used, and therefore the size to which the animal production develops, will depend upon the manner in which the energy obtained from the food itself is used. The energy input fed into an animal (Fig. 1) has to be shared between a number of processes, the relative demands of which, upon the energy capital, are not the same in all environments, or in all animal groups, or at all times of year. It has long been recognized that the activity, for example, of poikilotherms living in very cold circumstances is very much greater than our knowledge of temperature effects upon activity in warmer regions would lead us to expect. There must therefore be regulation, or adaptation, of the determinants of activity which allow the unexpectedly high level in cold regions. Such regulation may be, for all that is at present known about it, either genetically established or a matter of individual ontogenetic adaptation, but it is not difficult to imagine the high probability of the true evolution of such regulation, and its high selective value, since a minimum of activity is required for the business of food-getting and of escaping from predators which are not bound by this temperature condition (homotherms, especially large homotherms).

Regulation in activity with respect to temperature has led zoologists in the past to expect a corresponding, perhaps an enabling, regulation in standard metabolism, and there is evidence that this in fact occurs in many instances. The literature has recently been reviewed by Bullock (1955 (8)). Among the pioneers in the field are Fox (1936 (17*a*), 1939 (17*c*)), Wingfield (1939 (4*b*)); also Fox and Wingfield (1937 (18)) in England, and Thorson (1936 (43*a*), 1950 (43*b*), 1952 (43*c*)) and Spärck (1936 (41)) in Denmark. Thorson, studying the metabolic rates (measured by oxygen consumption) of inshore molluscs in east Greenland, Denmark, and the Persian Gulf, found that the rates were approximately equal in the same species or in closely related species living in the three regions, each being measured at its normal environmental temperature; thus if the arctic individuals were placed in water of normal Danish range of temperature, their metabolic rates were considerably higher than those of the Danish form, and the same, *mutatis mutandis*, for the Danish and Persian Gulf populations. Regulation thus appears to be common, or at least present in a number of species studied.

The work of Fox and Wingfield did not agree with that of Thorson, or of Spärck. Fox (1936 (17*a*)), working on the oxygen consumption of pairs of species (each pair being in the same genus) of echinoderms, annelids, and crustaceans, found that "for seven pairs of species inhabiting respectively English waters and more northern seas (Kristineberg in Sweden), the oxygen consumption of the warmer-water species is greater than that of the colder-water species (measured at the normal temperatures at which each species lives) although the locomotory activity of the former is apparently no greater". Fox suggested "that the similar locomotory activities of the two species require approximately equal amounts of oxygen, but that the non-locomotory oxygen consumption of the warmer-water species is higher than that of the cold-water species". The same results were found for two species of prawns (Fox and Wingfield, 1937 (18)). In this 1937 paper there is a note on the work of Spärck and Thorson, which appeared at the same time. Fox and Wingfield, in commenting on the disagreement between their results and the Danish work, point out that Spärck and Thorson were working on lamellibranchs, which were not used in the English work. Thorson (1952 (43*c*)), and also Berg (1953 (3)), have shown that the animals used in Fox's work were not truly comparable, on account of differences in size and age, and that if these factors are taken into consideration, then metabolic adaptation in the Kristineberg populations was in fact demonstrated.

Wingfield (1939 (46)) showed the danger of drawing too determined conclusions in this matter from comparisons of two different species (which has been the method used by many), by demonstrating that if the polychaete *Pectinaria granulata* from east Greenland is compared with *P. auricoma* from Millport it does not show metabolic regulation, but if compared with *P. koveni*, also from Millport, it does show regulation. Finally Scholander, Flagg, Walters, and Irving (1953 (38)), using this same technique of comparing groups from tropics and arctic which are more or less closely related taxonomically, found that in certain Crustacea there is evidence of metabolic adaptation,

the arctic forms showing somewhat higher metabolism than that which would have been expected simply by extrapolation from the tropical performances.

The species which have been studied are mainly shallow-water benthonic forms; there are as yet no data for the metabolic rates of holoplanktonic species in cold water. Research in this field is now urgently needed and is in fact being planned for the next *Calanus* expedition.

In poikilothermal vertebrates, Fry (1951 (19)) and his collaborators have shown that the speckled trout (*Salvelinus fontinalis*) is capable, individually, of a certain limited metabolic acclimation with respect to temperature, but there is no evidence yet that an established regulation exists in populations living in very cold water. Power (unpublished data), working on metabolic rates of the speckled trout at the northern limit of its range in northern Quebec, has so far found only very low rates which show little or no adaptive regulation. On the other hand Scholander, Flagg, Walters, and Irving (1953 (38)), comparing tropical with arctic fishes in this respect (interspecific and intergeneric comparison) found a considerable adaptation, the arctic species and genera lying in an intermediate position as regards oxygen consumption between the tropical fish and the "expected" or extrapolated position for fishes living at 0° C. Peiss and Field (1950 (29)) compared the oxygen consumption of excised brain and liver tissue of the polar cod (*Boreogadus saida*) with that of the golden orfe (*Idus melanotus*), and found that the Q_{10} values for the cod tissue remained steady over the whole temperature range of 0–25° C., whereas the values for the orfe tissue increased markedly below 10° C. This resulted in oxygen consumption values for the polar cod which were several times as great as in the orfe at low temperatures, clearly advantageous in the adaptation of the polar cod to cold environments. These experiments, however, showed a breakdown in metabolic adaptation in the orfe, the warm-water form, at low temperatures, rather than metabolic regulation in the cod.

There remains the question of growth rates. Both Bullock (1955 (8)) and Dehnel (1955 (9)) have observed that if growth in marine poikilotherms shows adaptation with respect to temperature, as has been shown to be the case for the metabolism in some species, then the high production of certain northern waters would be in large part explained. (It should be emphasized, however, that the high production is in the subarctic waters, not in the coldest, or arctic, regions.) Orton seems to have been one of the first to draw attention to the possibility of adaptation in growth rates. Writing in 1923, he refers to his earlier paper (Orton, 1920 (28*a*)) as drawing attention to the lack of evidence bearing on theories (those of Murray and Loeb, for instance) "to explain (*a*) the abundance of life in polar regions, and (*b*) the occurrence of several generations of species living side by side in polar waters". This latter point, the coexistence of several generations, can now be explained by the prevalence of two-phase or polyphase breeding cycles, such as have been demonstrated for euphausids, the chaetognath *Sagitta elegans* and the amphipod *Themisto libellula* (Ruud, 1932 (35); Dunbar, 1940 (11*a*), 1941 (11*b*), 1946

(11*d*) and this paper). Orton urges "(*a*) that we know nothing about the rate of growth of organisms in polar regions, and (*b*) that the kind of metabolism of animals in polar regions and in deep-sea situations is not necessarily the same as that in temperate and tropical regions".

Orton (1923 (28*b*)) found that sea urchins (identified as *Echinus miliaris*) observed in west Spitsbergen showed a rate of growth of the same order as is found in related forms in Plymouth waters in the English Channel. Again, this is the comparison of different species, not of populations of the same species. Thorson (1936 (43*a*)), studying lamellibranchs in east Greenland inshore waters, found slow growth rates, and generalizing from his work on the lamellibranchs, concluded "that the bottom invertebrates in the northeast Greenland seas will on the whole have a slow growth, a long life, and a late maturity which means that the production must be extremely small". He adds that this generalization is provisional, and that investigation of more species is necessary. Later (43*b*), finding that larval growth in arctic waters appears to be fast, he treats adaptive regulation of both metabolism and growth as a generally accepted phenomenon, and on those grounds dismisses Wimpenny's (1941 (45)) paper on "Organic polarity" as being out of date, since Wimpenny assumed that life cycles were shorter in tropical than in polar waters. He makes the observation that the *larvae* of benthonic invertebrates, northern as well as tropical, "seem on the average to spend a similar time (about three weeks) in the plankton", at the temperatures to which they are normally exposed, but he adds that in arctic regions abnormally low temperatures can have an adverse effect, and that "wastage caused by temperature, like that due to starvation, seems mainly to be an indirect one: low temperatures postpone growth and metamorphosis, and give the enemies a longer time to feed on the larvae".

Dehnel (1955 (9)) compared the growth rates, expressed as instantaneous relative rates, of the larvae of gastropod molluscs in southeastern Alaskan and southern Californian waters, and found that the rates for the northern populations were from two to nine times greater than for the southern populations of the same species over given ranges of temperatures. This comparison was intraspecific, populations of the same species being used. In spite of the fact that species with yolky telolecithal egg masses were chosen, to minimize the importance of food availability on growth, it is still possible that factors other than temperature were responsible for the fast growth of the Alaskan embryos, as Dehnel himself points out. Two other comments on these very interesting results are relevant here: (1) the surface temperatures of the southeastern Alaskan waters are not low when compared to arctic or even subarctic regions (the annual range at Sitka is from about 4° C. to 15° C.); and (2) the growth measured was embryonic and larval. It has been pointed out by several workers, including Thorson (1936 (43*a*), 1950 (43*b*)) that there are special problems for the colder-water benthonic forms, in that it is essential, for survival, that metamorphosis be accomplished within a certain short time after hatching, the time being determined by the length of the high production period in the phytoplankton, which is usually short in cold

regions, owing to the great stability of the surface waters in summer. Most arctic benthonic molluscs have solved this problem by eliminating the pelagic larval stage.

A high growth rate in embryonic development was also found by Fox (1938 (17*b*)) in sea urchins, those of British waters developing faster than those of the Mediterranean, at given temperatures.

The growth rates of larval and embryonic stages, however, are only a very small part of the problem. From the point of view of the student of production in the northern seas, the important thing is the time taken to reach maturity and breeding. Moreover, there is no reason to assume that what is found in the molluscs and in the echinoderms is true of all groups; and finally, the benthonic and littoral forms may behave quite differently in this respect from the holoplanktonic. Dehnel (1955 (9)) writes: "Generally, the assumption is made that species of marine poikilotherms which inhabit the colder waters of the higher latitudes grow more slowly, grow to a larger size, and have a greater longevity than individuals of the same or closely related species from warmer waters". In fact, this is much more than an assumption, as Dehnel indicates later in his paper. There is a great deal of evidence in the literature for the slowing down of growth rates in cold water as compared with warm, not only in the comparison of different species within one genus but also in the comparison of different populations within one species. Thus Schneider (1891 (37)) concludes that several of the common gammarid amphipods of the Tromsö coast have a 2-year life cycle, some even longer, and comments that increase in life-time, and time taken to reach maturity, with increasing geographic latitude is a well-known phenomenon in insects. In the Lepidoptera, for instance, many species have a 1-year life cycle in Germany and a 2-year cycle in Norway. Schneider mentions also the tiger-moth, *Arctia caja*, which lives 1 year in the Oslo area but which requires 2 years to reach maturity at Tromsö.

In the chaetognath *Sagitta elegans*, Russell (1932 (34)) recorded four, possibly five broods, produced in 1 year at Plymouth, each brood being parental to the next. In the same species in Baffin Island waters, Dunbar (1941 (11*b*)) found the normal life cycle to be probably as long as 2 years before spawning. Bogorov (1940 (5)) found a 2-year life cycle for both *S. elegans* and *Eukrohnia hamata* in the Barents Sea. In the Euphausiidae, Macdonald (1928 (23)) recorded a breeding cycle in *Thysanoessa raschii*, in the Clyde Sea area, which appeared to involve a 1-year life cycle. Einarsson (1945 (13)) also found a 1-year cycle for the same species in southern Icelandic waters, but concluded that in northern Iceland and in west Greenland *T. raschii* took 2 years to reach maturity. Bogorov (1940 (5)) recorded a 2-year cycle for *Thysanoessa inermis* and *T. longicaudata* in the Barents Sea. In the deep-water shrimp *Pandalus borealis*, Hjort and Ruud (1938 (22)) concluded that maturation (to maleness) occurred in the second summer of life in Norwegian waters; in the same species Rasmussen (1942 (30)) described a 3-year maturity age in Spitsbergen.

The copepod *Calanus finmarchicus* has been exhaustively studied. The researches have recently been reviewed and consolidated by Marshall and Orr (1955 (25)), who write (p. 64): "As is natural, the lower the temperature the slower is the rate of development, and the later does the first spawning occur". In the Clyde Sea area, where the temperature at the time it is homothermic in March is about 7° C., *Calanus finmarchicus* spawns at least three times during the period between mid-February and late July. Thus the life span in spring is about 2 months. The winter stock may live up to 7 months. In east Greenland (Digby, 1954 (10*b*)), where the winter temperature is about −1.5° C. for a considerable period, the same species spawns only once a year, in midsummer, and the individual normal life span is therefore 1 year. There is evidence that a proportion of the population may survive a second winter. In Ungava Bay, Fontaine (1955 (16)) found 1-year life cycles in *Calanus finmarchicus* and *Pseudocalanus minutus*. Other planktonic copepods follow the same pattern. Digby (1954 (10*b*)) comments that in view of this, copepods in the arctic cannot be considered to be particularly well adapted to living in cold seas. There is, however, some likelihood that the availability of food may be an important factor, besides temperature, in determining the growth rate.

An exception to this apparent rule of slower growth in colder water was reported by Moore (1934 (26)), who found that the common barnacle, *Balanus balanoides*, has a faster growth at Herda, in Norway, than at Port Erin in the Irish Sea, where the growth was in turn faster than at St. Malo in France.

In vertebrate poikilotherms the evidence is confusing, as indeed it is also in the invertebrates. The arctic char (*Salvelinus alpinus*) in Frobisher Bay, Baffin Island, takes 12 years to reach maturity in the female (Grainger, 1953 (20*a*)). The Atlantic cod (*Gadus callarias*) of Port Burwell, Ungava Bay, grows considerably more slowly than the cod of west Greenland, Newfoundland, or Nova Scotia (Dunbar, unpublished). In these instances there is no evidence that the food supply is involved. In the Amphibia, however, the work of Moore (1939 (27*a*), 1942 (27*b*), etc.) has shown that the embryonic development of species of *Rana* is faster, the colder the environment, the northern *Rana sylvatica* developing at about twice the rate of the southern *Rana catesbeiana*. Differences in the type of life cycle are probably at the root of the ultimate (as opposed to the proximate) causes for the differences between groups in this respect, which, as has been suggested above is the case between the benthonic invertebrates and the holoplanktonic forms.

Material and Methods

The hyperiid amphipods have been given scant attention biologically. The tropical and temperate species are difficult taxonomically and appear to be of secondary importance in the economy of the seas. The cold-water species, however, *T. libellula* in particular, are abundant and often dominant. As a group the hyperiids are well suited to studies of the present sort, being large, easily caught, holoplanktonic or holopelagic, with direct development.

Themisto libellula is a dominant species of the plankton of the waters of Hudson Strait, north and east Baffin Island, and Hudson Bay. Its ecological position farther north is not yet known (it is not abundant in Foxe Basin), but it appears to be arctic rather than subarctic, being not common in the west Greenland waters except in their northern part. It extends, however, into the subarctic on the Canadian side, decreasing in abundance southward along the Labrador Current. In the subarctic it can be relied upon as an indicator of arctic water. It has been recorded from all arctic seas explored, except that information from the Arctic Ocean itself is lacking. The most southerly records are the Strait of Belle Isle (Bousfield, 1951 (6)), off Cape Farewell and the southeast coast of Iceland (Stephensen, 1923 (42)), the Norwegian, Barents, and Murmansk seas, Kara Sea, Bering and Okhotsk seas (Behning, 1939 (2)).

The species figures prominently in the food of the arctic char (Grainger, 1953 (20)), and especially of the ringed seal (Dunbar, 1941 (11*c*)). It forms the most important link in the food chain between the copepods and other smaller planktonic forms on the one hand, and the vertebrates on the other, and in fact it takes the place, in cold water, of the euphausids in this respect.

The material used in the present paper was collected on the *Calanus* Expeditions of 1947 to 1955, the details of the collection being shown in Tables I and II. Open plankton nets were used, and most of the *Themisto* were taken in horizontal hauls. The nets were the 1- and 2-meter stramin nets, a half-meter No. 6 net and No. 5 net of the same size, and 1-meter No. 0 and No. 00 nets. Depths of hauling are approximate only, being calculated from the wire angle and the length of wire. An error of about 10% can be expected in the depth calculations. Material was also obtained from stomachs of the ringed seal (*Phoca hispida*) in the waters of southwest Baffin Island (Cape Dorset) and from Igloolik in Foxe Basin; and from stomachs of arctic char at the head of Frobisher Bay.

TABLE I

COLLECTION DATA FOR THE *Themisto libellula* MATERIAL (IN THE "NET" COLUMN, NUMBERS REFER TO THE BOLTING SILK GRADE, EXCEPT THAT "STR. 1" MEANS "1-METER STRAMIN; "STR. 2", "2-METER STRAMIN")

Year	Date	Station	Depth, m.		Net	Time, E.S.T.	Duration, min.	Numbers	
			Station	Haul				Taken	Measured
1947	24/6	1	18–31	5	6	1420	25	7	7
	29/6	3	28	2	Str. 1	1100	30	2	2
	29/6	3	28	4–5	6	1104	25	9	9
	29/6	3	28	5–7	0	1104	25	42	41
	13/7	13	46–55	6	0	1000	30	80	80
	17/7	18	84	17–21	0	1240	30	50	50
	10/8	33	15	11–13	Str. 1	0810	30	2	2
	10/8	33	15	11	0	0810	30	9	9
	11/8	37	3–4	0	6	1040	30	1	1
	11/8	37	3–4	0	Str. 1	1048	30	1	1
	17/8	41	240	27–35	6	1300	60	1	1
	17/8	41	240	200	0	1300	60	15	15
	17/8	41	240	54	Str. 1	1300	60	Several hundreds	2
	19/8	44	80	70	0	1330	40	1	1
	19/8	44	80	70	Str. 1	1334	36	18	18
1949	26/6	101	18	6–8	Str. 1	1045	30	8	8
	26/6	101	18	1	6	1055	30	3	3
	6/7	103	145–275	90	00	—	20	20	20
	6/7	103	145–275	200	Str. 1		45	14	14
	14/7	103	145–275	105	Str. 1	0930	45	44	44

Year	Date	Station	Depth, m. Station	Depth, m. Haul	Net	Time, E.S.T.	Duration, min.	Numbers Taken	Numbers Measured
1949	7/8	103	145–275	5–10	00	1120	12	9	9
	10/8	123	15	1–7	5	1515	35	1	1
	10/8	123	15	5–10	00	1645	22	3	3
	21/8	125	18	0	Str. 1	—	90	1	1
	23/8	126	70–90	2–10	Str. 1	1057	35	37	37
	24/8	128	185	27	00	1445	70	43	43
	24/8	128	185	137–162	Str. 1	1455	70	25	25
	25/8	129	–	16–19	Str. 1	1340	60	3	3
	25/8	129	–	3	00	1340	60	3	3
	25/8	129	–	13–15	6	1345	50	4	4
1950	28/6	201C	80–100	1	00	0935	55	11	11
	28/6	201C	80–100	20	Str. 1	0955	20	13	13
	15/7	206	55–90	3	Str. 1	1020	45	60	60
	20/7	209	183	75	Str. 1	1305	25	78	78
	3/8	222	80–90	8	5	1800	20	42	42
1951	4/7	303	120	–	Str. 1	1715	30	64	64
	28/7	309	165	75–87	Str. 1	2000	30	43	43
	14/8	326	550–640	225	Str. 1	1015	60	139	139
	21/8	329	183	150	Str. 1	1153	50	47	47
	26/8	335	320	50	Str. 1	1715	15	55	55
	26/8	335	320	92	Str. 1	1715	15	11	11
	26/8	335	320	155–215	Str. 1	1855	30	90	90
	26/8	335	320	0	0	2016	15	24	24
	26/8	335	320	50	Str. 1	2016	15	77	77
	26/8	335	320	92	Str. 1	2016	15	115	115
	26/8	335	320	0	0	2312	15	192	192
	26/8	335	320	50	Str. 1	2312	15	72	72
	26/8	335	320	92	Str. 1	2312	15	67	67
	26/8	335	320	154	Str. 1	2352	30	86	86
	27/8	335	320	0	0	0209	15	207	207
	27/8	335	320	50	Str. 1	0209	15	48	48
	27/8	335	320	92	Str. 1	0209	15	46	46
	27/8	335	320	20–25	Str. 1	0250	15	105	105
	27/8	335	320	250	Str. 1	0407	15	30	30
	27/8	335	320	0	0	0505	15	7	7
	27/8	335	320	50	Str. 1	0505	15	10	10
	27/8	335	320	92	Str. 1	0505	15	3	3
1952	29/7	407	228	115	Str. 1	1010	15	12	12
	29/7	407	228	10	5	1122	15	12	12
	2/8	411	83–91	0	18	0920	12	48	48
	5/8	414	275–365	105	Str. 1	1810	35	216	216
	6/8	416	275–285	115	Str. 1	1535	20	37	37
	6/8	416	275–285	175	Str. 1	1620	45	512	512
1953	13/7	502	22–27	20	0	1615	10	21	21
	21/7	503	65–90	35	0	1520	25	86	86
	21/7	503	65–90	17	Str. 2	1700	15	53	53
	31/7	514	20	9	0	1703	30	15	15
	4/8	520	137	87	0	1250	30	55	55
	4/8	520	137	40–52	Str. 2	1615	15	Several hundred	121
	9/8	527	355–415	62	0	1110	20	43	43
	11/8	531	183	62	0	1710	25	16	16
	17/8	535	140–155	7	5	1320	15	66	54
	4/9	549	75	7	5	1210	20	63	63
	4/9	549	75	46	Str. 2	1345	15	43	43
	8/9	512	21	14	Str. 2	1440	25	32	32
	8/9	512	21	15	0	1545	20	49	49
1954	24/7	603	90–110	40	Str. 2	1600	30	6	6
	25/7	603	90–110	26	Str. 2	1721	15	Several hundred	76
	5/8	606	99	26	Str. 2	0000	30	87	87
	5/8	606	99	43–65	Str. 2	0140	15	265	265
	12/8	613	189	78–115	Str. 2	0955	30	175	175

TABLE II

COLLECTION DATA FOR *Themisto libellula* MATERIAL FROM STOMACHS OF RINGED SEAL (*Phoca hispida*)

Year	Date	Location	Number measured
1953	23/8	Cape Dorset	230
1954	22/3	Cape Dorset	315
1954	13–19/7	Cape Dorset	184
1955	27/10	Igloolik	112
1956	31/1	Igloolik	3
1956	27/2	Igloolik	17
1956	28/2	Igloolik	10

The 1947 and 1949 material comes entirely from Ungava Bay; the 1948 material consists of a collection of *Themisto* taken from the stomachs of arctic char at the head of Frobisher Bay (see map Fig. 2). The 1951 collection is in the main from Frobisher Bay, 1952 from Cumberland Sound. (For the identification of the stations in Table I, see the station lists already published (Dunbar and Grainger, 1952 (12); Grainger, 1954 (20*b*); Grainger and Dunbar, 1956 (21).) The 1953 and 1954 material is from northern Hudson Bay and the western end of Hudson Strait. Collections from ringed seal stomachs in 1953 and 1954 are from the region of Cape Dorset, southwest Baffin Island (August 1953, March and July 1954), and the material from October 1955 to March 1956 is taken from ringed seals off Igloolik, in the north of Foxe Basin.

Measurements were made with a low-power binocular microscope, the specimens being placed on a thin glass slide over a half-millimeter scale. The over-all lengths, from the front of the head to the tip of the longest uropods, were read to the nearest quarter-millimeter and then grouped on integer centers, all individuals from $x \cdot 5$ to $(x+1) \cdot 25$ being grouped under $(x+1)$ mm. The length frequencies of the samples are presented in the histograms (Figs. 3 to 5 and 11 to 13).

FIG. 2.

The Environment

The detailed hydrography of the area will be published in a paper to appear shortly in this series. Hudson Bay, Foxe Basin, and the western part of Hudson Strait are arctic areas in which the influence of Atlantic water is minimal if indeed it is present at all. Frobisher Bay, although probably containing a small proportion of west Greenland water, with Atlantic admixture, in the summer, is nevertheless predominantly arctic. Ungava Bay, on the other hand, shows considerable Atlantic influence, both hydrographically and in its fauna. It is an unstable region with very large tidal intervals and is slightly warmer below 25 meters than the rest of the region considered here. July temperatures in Hudson Bay and Hudson Strait (western part), below 25 meters, are normally below −1° C., whereas they range from −1.5° C. up to about +1.5° C. in Ungava Bay. In August, the 50-meter water may be up to 2° warmer in Ungava Bay than in the rest of the region, including Frobisher Bay. The 100-meter water in August in Ungava Bay is similar in temperature range to the water at the same depth in Froblisher Bay, between 0° and −1° C., and about 0.5° warmer than the Hudson Bay level, where the 100-meter water is below −1.0°. Hudson Bay, being highly stratified in summer owing to the influx of fresh water from the large land area it drains, is distinctive in having the surface water warmed up to the level of about 10° C. As far as the present paper is concerned, however, these exceptional temperatures are of no significance, since *Themisto* is apparently inhibited by them from invading the surface layers.

Growth Rate and Breeding Cycle

In an earlier paper on *Themisto* in Baffin Island waters (Dunbar, 1946 (11*d*)) it was shown that the size frequencies of the samples were strongly bimodal, the two size-groups being statistically quite separate and therefore representing two separate broods. The same bimodal distribution is demonstrated in the present material, shown in Figs. 4, 5, 11, and 12. The division between the two groups occurs, in the summer period of collecting, at about 20 mm.

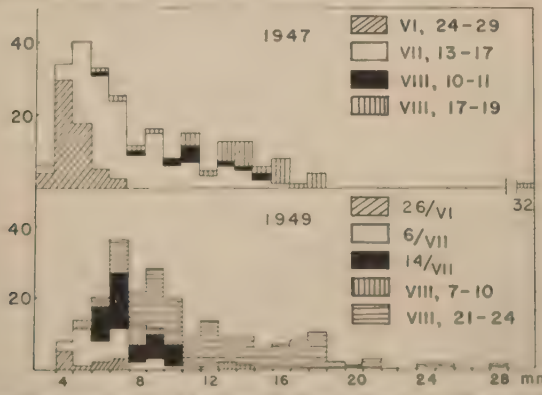


FIG. 3. Size distribution in *Themisto libellula* taken at different times during the summer seasons of 1947 and 1949, Ungava Bay.

In the separation of the broods for statistical treatment, the lowest point in the distribution has been taken, and this point is seen (Fig. 12) to coincide with the point at which, in the ascending series of length, adolescent individuals begin to appear, in contrast to the juvenile population to the left of the low point.

Figs. 3, 4, and 5 show the material from 1947 and 1949 (Ungava Bay), 1951 (Ungava Bay, Lake Harbour, and (predominantly) Frobisher Bay), and 1953 (northern Hudson Bay, and the western end of Hudson Strait), arranged according to date of collecting, to demonstrate change in size during the sum-

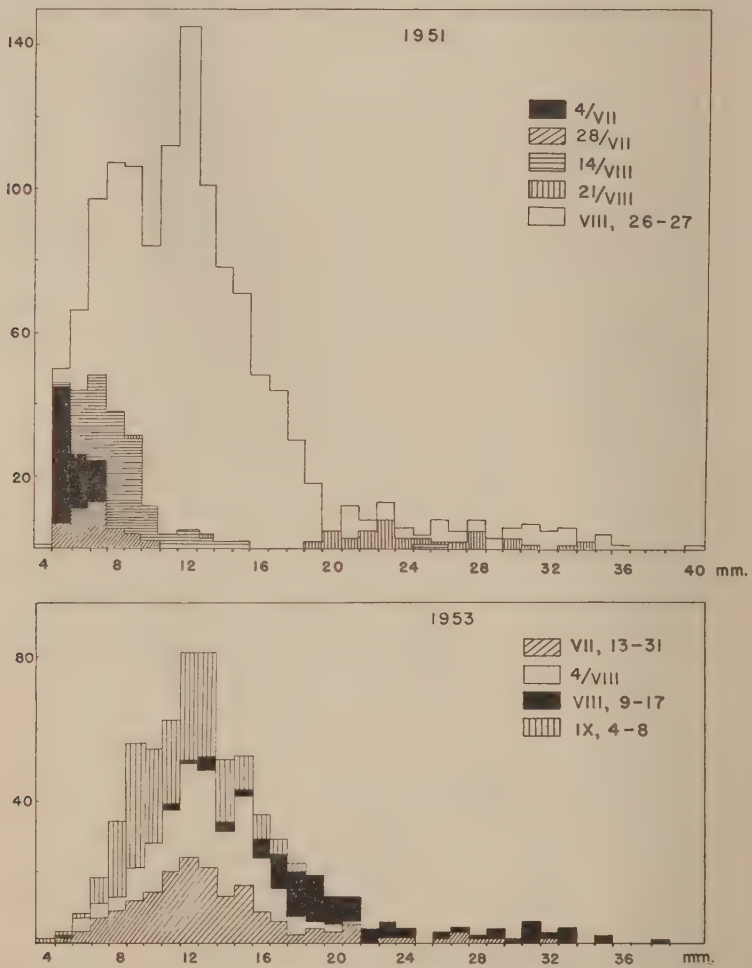
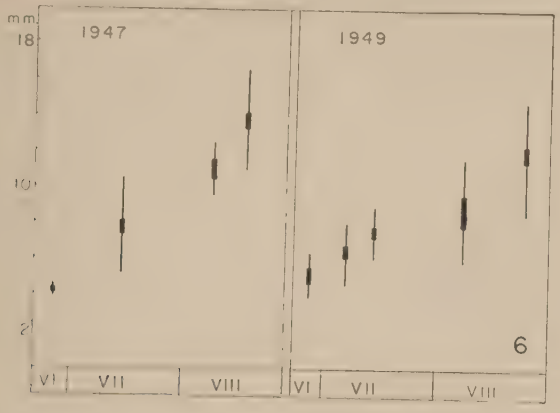


FIG. 4. Size distribution in *Themisto libellula* taken on 5 days in 1951, in Ungava Bay (4/VII), Lake Harbour (28/VII), and Frobisher Bay.

FIG. 5. Size distribution in *Themisto libellula* taken at different times during the summer season of 1953, in northern Hudson Bay and the western entrance of Hudson Strait.

mer season. In Figs. 6, 7, and 8 the increase in body-size in the populations is shown graphically on either side of the mean by lines representing one standard deviation (thin lines) and one standard error (thick lines), the total length of each line being therefore two standard deviations.



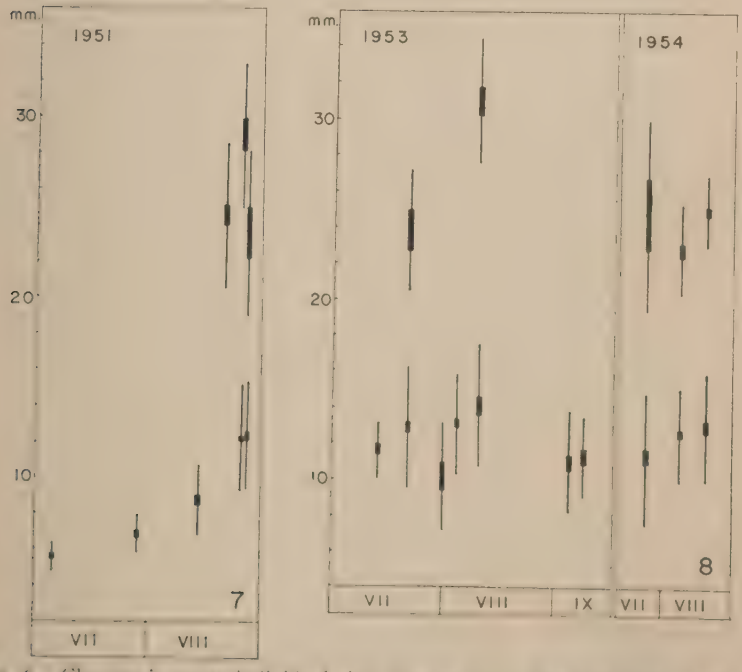
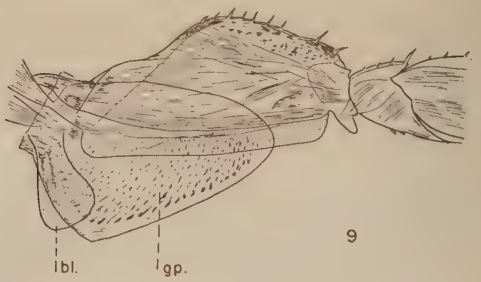


FIG. 6. Changes in mean individual size, Ungava Bay, 1947 and 1949. The total length of the vertical lines represents two standard deviations, that of the broad section two standard errors. Months on the horizontal axis.

FIG. 7. Changes in mean individual size, Ungava Bay (early July), Lake Harbour (late July), and Frobisher Bay (August). (For details see Fig. 6.)

FIG. 8. Changes in mean individual size, 1953 (northern Hudson Bay and west entrance of Hudson Strait), and 1954 (Hudson Bay). (For details see Fig. 6.)



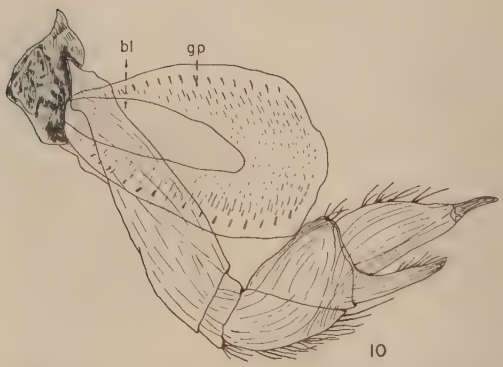


FIG. 9. Part of the fifth peraeopod of a female in the stage referred to as "adolescent" in the text.

Abbreviations: bl., brood lamella; gp., gill plate.

FIG. 10. Second leg of a female in the "maturing" stage, in which the brood lamella (bl.) is increasing in size.

Abbreviation: gp., gill plate.

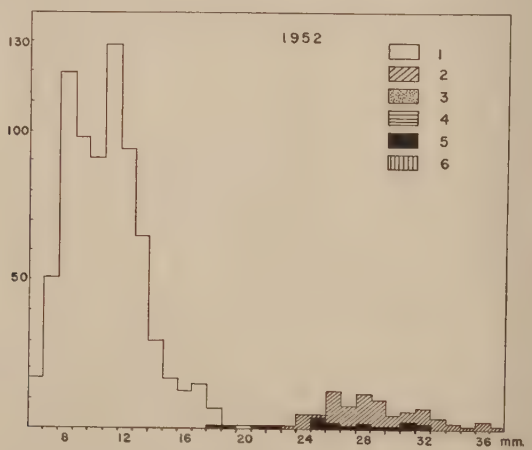


FIG. 11. Size distribution of *Themisto libellula* from Cumberland Sound, 1952, showing maturity stages.

The key refers to Figs. 11, 12, and 13; (1) immature; (2) "adolescent" females; (3) "maturing" females; (4) mature females; (5) adolescent males; (6) mature males. Vertical axis, numbers of individuals; horizontal axis, length in mm.

The material from 1952 (Cumberland Sound), 1954 (Northern Hudson Bay), and from stomachs of the ringed seal (Cape Dorset area, 1953, 1954, and Igloolik, 1955) has been divided into maturity stages, and the results shown in Figs. 11, 12, and 13. The stages are based on the development of the brood lamellae, or oostegites, in the female, and on the growth of the antennae in the male. Mature specimens were not taken in the net hauls, and the seal stomach material was too far digested to allow the use of the ovaries and testes. The delimitation of the stages is as follows:

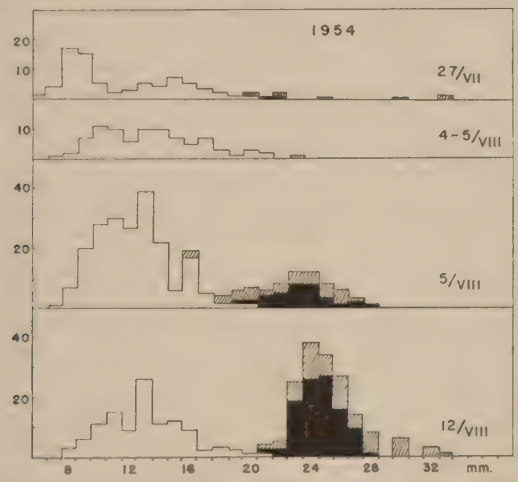


FIG. 12. Size distribution of *Themisto libellula* from northern Hudson Bay, 1954, taken on various dates, showing maturity stages. (Details as in Fig. 11.)

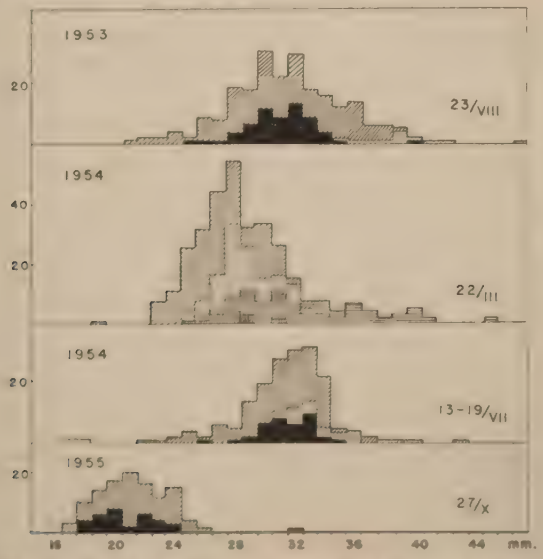


FIG. 13. Size distribution of *Themisto libellula*, with maturity stages, from ringed seal stomachs, 1953, 1954: Cape Dorset; 1955· Igloolik.

Immature: Antennae very short, no sign of development of oostegites.

Adolescent female: Oostegites present, but rudimentary, as in Fig. 9. Ovaries small, usually less than 5 mm. in length, cells very small.

Maturing female: Oostegites increasing in size from the "adolescent" condition (Fig. 10). Ovaries larger, with cells about 0.2 mm. in diameter or larger.

Mature female: Oostegites fully developed, almost twice the length of the gill plates. Specimens often with eggs or young in the brood pouch.

Adolescent male: Antennae increasing in length (Dunbar, 1946 (11*d*), Fig. 5).

Mature male: Antennae fully developed, the first antennae reaching to the hind margin of the first pleonal segment, the second antennae reaching beyond the hind margin of the last pleonal segment.

It has been demonstrated (Dunbar, 1946 (11*d*)) that in *Themisto libellula* there is an alternating or two-phase breeding cycle, such that two generations, or broods, exist at the same time, the two broods being apparently isolated from each other so far as reproduction is concerned, unless the cycle goes out of phase or unless a few individuals breed twice. During the breeding period itself, three broods are present, the breeding group, the adolescent group, and the very young group which is being produced at the time. Breeding cycles of this sort have also been shown to be the rule in certain other cold-water pelagic forms. It was not clear, however, from the earlier work, whether there were breeding periods in the fall and in the early part of the year (March–May), in which case the length of life would be 1 year, or whether there was only one breeding period, in which case the length of life would of necessity be 2 years at least.

Figs. 6, 7, and 8 are not growth curves; they show the manner in which the size-frequencies of *Themisto* in the plankton samples change as the summer advances. It will be seen that in 1947 and 1949 (Ungava Bay) and in 1951 (predominantly Frobisher Bay) there is an orderly progression of advancing average size in the youngest, or juvenile, group. This increase is less clear in the 1954 material, and in 1953, also from Hudson Bay, the slope is definitely reversed by the reduction in average size of the population in September. Fig. 5, dealing with the same 1953 population, shows that this effect in September is caused by the entry into the sample of numbers of very small individuals, down to 4 mm. in length, recently freed from the parental brood pouch. A similar arrival of very small specimens, this time in late August, is also shown in the Frobisher Bay collection of 1951 (Fig. 4), but here the average size of the juvenile population is not reduced compared to samples from earlier in the season owing to the presence of large numbers of larger juveniles, up to 19 mm. in length. There is no such late appearance of small individuals within the collecting season (June–August) in Ungava Bay (Fig. 3).

Another important difference between the Ungava Bay samples on the one hand and those from Frobisher Bay, Hudson Bay, and western Hudson Strait on the other is the almost complete absence of the larger (adolescent) group in Ungava Bay. In the net plankton, only one individual taken in 1947 belonged to the adolescent group, and only nine in 1949. The ringed seal

(*Phoca hispida*) feeds habitually on the larger individuals of the *Themisto* population (Dunbar, 1941 (11*c*)) yet of 36 ringed seals taken in the 1947–1950 seasons, only 10 had *Themisto* in the stomach, and those 10 had a total of only 36 specimens between them. Of these 36 specimens, only one half were over 20 mm. in length, and the largest was only 25 mm. This is in strong contrast to the seal stomachs taken at Lake Harbour, Frobisher Bay (Dunbar, 1941 (11*c*)), and in the Cape Dorset area (McLaren, in press), which were frequently found to be full of *Themisto libellula*, often to the exclusion of other food organisms. A swarm of adolescent individuals was observed and sampled in 1948 at the western end of Ikeresak, or McLelan Strait, which separates the island upon which Port Burwell is situated from the mainland of Labrador, but in that highly turbulent region it is impossible to determine where the swarm came from or whether it represented a permanent population. The evidence is in favor of the conclusion that *Themisto* does not breed in Ungava Bay, that the juvenile population is brought into the bay from the northwest, in the Hudson Strait outgoing current, and that it is swept out of the bay again before it reaches adolescence; or that it does not survive within the bay for some other reason. There are in fact certain hydrographic differences between Ungava Bay and the rest of the area examined here which are referred to above and which might be adequate to explain the matter.

Not one mature specimen, male or female, was taken in the plankton nets in any season. The maturity stages of the net catches of 1952 and 1954 are shown in Figs. 11 and 12, and they are typical of all years. Nor were there any mature specimens taken in seal stomachs in summer. As shown in Fig. 13, however, seal stomachs taken in March 1954, in the Dorset area, contained mature males and females, and mature females occurred in stomachs taken in February 1956 at Igloolik. Stomachs examined in August 1953 and July 1954 contained females in the maturing condition. The absence of maturing females from the net hauls is unexplained. It is improbable that individuals of this size can escape a 2-meter stramin net hauled at 3 knots, especially at night; it may be, however, that the maturing females maintain a lower level of vertical distribution than the others, although the net was lowered close to the bottom on several occasions and hauled obliquely, still without taking the maturing individuals.

Mature females, with and without eggs and young in brood pouches, were taken only in late January, February, and March. The young are released at a size of 2 to 3 mm. In the present series no collecting was done earlier in the winter than the end of January, and summer field work was carried out only between late June and early October. However, since the juvenile samples taken in June and early July show a fairly wide range of body length, and include individuals of only 4 mm., it may safely be assumed that the breeding period extends over a considerable period and that new broods are still being shed in the first half of June. The absence of spent individuals in spring and summer is evidence that each individual breeds once only (see below). We do not know how long the young are retained in the brood pouch.

One mature male was taken in the stomach of an arctic char in Frobisher Bay in August 1948 (precise date in August not given). This was an individual 31 mm. in length with antennae fully developed (first antenna 17.5 mm., second antenna 20.5 mm.), with sexual papillae developed, and with the testes silvery, rounded, and swollen and the seminal duct darkly pigmented. Another male 22 mm. in length had a second antenna 11 mm. long, first antennae missing. The females in the char stomach material from the same month were not mature, but some were in the "maturing" category, up to 32.5 mm. in length.

The presence of the mature male in August, the maturing females in seal and char stomachs in July and August, the one mature female taken in a seal stomach in October 1955 at Igloolik (Fig. 13), and the recruitment of very small juveniles into the stock in late August 1951 (Fig. 4) and early September 1953 (Fig. 5)—all indicate that breeding begins in the late summer and early fall. It is possible that this autumn breeding period is less important than the breeding period in the early part of the year. However, the lack of material in November, December, and January makes it impossible to rule out the possibility of a sustained breeding period throughout the winter, from September perhaps to June, and indeed for the greater part of the year.

Themisto libellula does not appear to be abundant in Foxe Basin, but there is a little material from ringed seal stomachs taken at Igloolik in January and February 1956, which is helpful. From January 31 there are three measurable specimens, 28, 30, and 31 mm. long, all with fully developed oostegites, and parts of 13 other specimens of similar size. From February 27 there are 20 specimens, one male of 27.5 mm. with the antennae broken but clearly well developed, and 19 females of which three are not measurable. The remaining 16 range from 20.0 to 35 mm. in length, and they all have fully developed oostegites, some with eggs and early young. The small size of the smaller of these specimens (20–21.5 mm.) suggests that at least some of the juveniles of each year may come into breeding condition the following winter. From February 28 there is a collection of 11 specimens of which nine are mature females ranging from 26 to 36 mm., one is a mature female of similar size with the head missing, and one is a juvenile of 11 mm. Clearly spawning has started by the month of February if not before, and although it is improbable that many of the juveniles of the year breed in the following winter, some apparently do, as shown by the small specimens taken on February 27, 1956. Most of the breeders each winter, however, must be the adolescents of the previous summer; indeed, the strong bimodality of the size-frequencies in summer makes it impossible that many of the juveniles should breed the winter after they are produced. This means that the life cycle of the individual is between 18 months and 2 years, but that a life cycle of 1 year is not impossible. This argument is illustrated in Fig. 14, and rests on the assumption that each individual breeds only once. The fact that a 1-year life cycle is possible means that the reproductive isolation of the two coexisting year-classes is not complete.

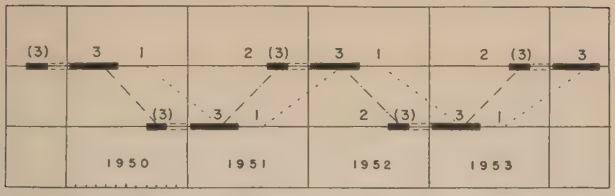


FIG. 14. Schematic diagram representing the probable breeding cycle of *Themisto libellula*. The two horizontal lines represent the time-continua of the two populations which exist together in the same space, between which reproductive contact is probably quite small, or absent. The heavy black portions represent the breeding periods; (1) immature group; (2) adolescent group; (3) mature breeding group. The possible extension of breeding throughout the long winter is indicated by the horizontal dotted lines. The diagonal lines represent the cases in which the alternating cycle may go out of phase either by the holdover of breeding until the fall, or by the precocious maturation of small individuals (Group 1).

Discussion

1. The question of whether *Themisto libellula* breeds more than once in its life is obviously highly important in reaching an understanding of the breeding cycle. The evidence on this point is not entirely conclusive, and in the past there has been some difference of opinion on this point as regards the amphipods as a group. Schneider (1891 (37)) quotes three authorities on the question and gives some observations of his own. Thus Siebold and Stannius (1854 (40)) describe the brood lamellae or oostegites of the female amphipod as developing rapidly at the approach of the breeding season and later disappearing or becoming atrophied. Bate (1856 (1)) considered that there was no evidence for the loss of the brood lamellae. Bruzelius (1859 (7)) was willing to allow the possibility of decrease in size of brood lamellae after breeding, but did not believe that they disappeared completely. Schneider himself pointed out that all three authors appeared to have assumed that amphipod individuals breed more than once, but that there was no evidence of that. He suggested that the absence of spent specimens, and of large females without oostegites, could most simply be explained by supposing that breeding only once per lifetime was normal, as it is in insects.

Blegvad (1921 (4)) records "*Gammarus locusta*" (probably *G. zaddachi*) as breeding seven or eight times per female in Danish waters, within a short time in one breeding season, and finds that the stock produced after the month of May can breed in two seasons: that is, after breeding once in late summer they may survive the winter and breed again the following spring. In Segerstråle's (1950 (39)) paper on the amphipods of Finnish waters, on the other hand, there is no indication that *Gammarus zaddachi* (or its "*salinus*" form) breeds more than once; the cold-water *Gammarus oceanicus*, similarly, appears to breed only once per individual.

In the present study it has been concluded that the *Themisto libellula* individual breeds once and dies. There is no evidence whatsoever to the contrary. No spent specimens of either sex were taken, except in March at the height of the breeding season.

2. The stimulus for the final ripening of the gonads and the onset of the breeding, if it has anything to do with temperature at all, appears to involve a fall rather than a rise in temperature. Orton (1920 (28)) suggested that "Most animals under normal conditions begin to breed either at a definite temperature, which is a physiological constant for the species, or at a definite temperature change, namely at either the maximum or the minimum temperature of the locality", and added that many continued to breed so long as the temperature remained above or below a certain figure, critical for each species, and that a given species might be a winter breeder in warmer situations and a summer breeder in colder areas, a situation which appears to be illustrated in the invertebrate fauna of Norwegian waters, where the northern elements breed in the winter and the southern elements in the summer (Ekman, 1953 (14)). Orton took the argument further: "It follows that in those parts of the sea where temperature conditions are constant or nearly constant, and where biological conditions do not vary much, marine animals will breed continuously". He suggested that this condition might be found in the arctic. In the abyssal depths of the sea, where there may well be no seasonal variation in temperature, breeding all year may well be the case, as is stated, apparently on rather slim evidence, by Reibisch (1927 (31)), although even in the abyssal region there must be a seasonal variation of the food supply, which comes from the surface layers. On the other hand, year-round breeding is known to occur in species where habitats certainly do show considerable seasonal temperature variation, as in *Gammaris zaddachi zaddachi* on the coast of Finland (Segerstråle, 1950 (39)). In arctic waters, however, Orton's prognostication has not been realized. All arctic and subarctic forms so far studied have shown well-marked breeding periods, often extending over only a short part of the year. Indeed, year-round breeding appears to be far more common in *tropical* waters, not in the arctic.

There is to begin with a significant variation in the annual temperature cycle at the depths in which the animals of the arctic and subarctic continental shelf live. Thus in Godthaab Fjord, a decidedly subarctic region as opposed to arctic, the annual range of temperature at 75 meters is of the order of 1° C. to 2.75° C. (Dunbar, 1946 (11*e*)). Surface temperatures of course show a wider range, but they are not ecologically significant in the present argument. In Scoresby Sound, east Greenland, Digby (1953 (10*a*)) recorded, at 50 meters, −0.95° C. at the beginning of October, −1.78° in January, and −1.47° at the end of July. From November to May inclusive the temperature was not above −1.72° C. at 50 meters depth. In the waters of northern Baffin Island, Ellis (1956 (15)) measured, again at 50 meters, temperatures of −0.90° C. in September and October, −1.00° in November, −1.05° in December, −1.70° to −1.75° in April and again in June, −1.65° in late June, and −1.45° in July. A similar cycle was recorded at Igloolik by the *Calanus* wintering expedition of 1955–56: from November through the winter and spring to June, the temperatures at 50 meters were below −1.70° C.,

in July rose to −1.63°, in August to −0.07°, and in September the temperature measured was −0.24°. Hudson Bay conditions are essentially similar. In the area between Southampton Island, Coats Island, and Mansel Island temperatures at 50 meters in July and August range from −1.50° to about 0.05°, and in the months of April, May, and June they are below −1.70° down to −1.80° C. Winter temperatures in Frobisher Bay and Ungava Bay are not known, but the upper 50 75 meters in Ungava Bay in summer are both warmer and less stable, temperatures as high as 2.16° C. having been recorded.

The coldest time of the year, therefore, in the depths at which *Themisto libellula* lives, in arctic regions, is from November to June inclusive, when the temperature is close to its "floor" level of about −1.70°. From July to early October temperatures are about 2° higher. Therefore, if temperature controls the onset of breeding, and since *Themisto* breeds in the coldest part of the year, it is indicated that the stimulus is a fall below certain threshold value and not a rise above it. However, the fact that breeding begins, apparently, in September, close to the warmest part of the year in the water, suggests that the temperature threshold is not the overriding or efficient stimulus, but that some other factor such as light is involved. It is possible that the autumn breeders should be considered as "hold-overs" from the end of the previous winter, breeding late for one reason or another, and that they are not in the normal physiological condition. More information is needed on the winter biology of the species.

It is well known that arctic species which extend south into the boreal region tend to breed during the winter, but it is not yet established that winter breeding in the arctic itself is a common habit. As a winter breeder of egregiously arctic affinities, *Themisto libellula* contrasts with another important member of the arctic pelagic fauna, *Sagitta elegans arctica* Aurivillius, which breeds in the summer (Dunbar, 1941 (11*b*)), and with the planktonic copepods (Fontaine, 1955 (16); Digby, 1954 (10*b*)). Samter and Weltner (1904 (36)) reported of *Mysis relicta* in Europe that it produced eggs only in cold water, below 7° C., and that the chief production was in the winter, at temperatures between 0° and 3° C.

The appearance of large numbers of very small amphipods released from the parental brood pouches in the dead of winter raises the question of what they eat. The density of the visible or sedimentable phytoplankton during the winter is extremely low, and the first sign of phytoplankton development at Igloolik during 1955 56 did not appear until the first half of May (Grainger, unpublished). Two possibilities remain: either the young feed almost entirely on detritus, perhaps close to the bottom or on it, or else there must be a continuing production of microplankton which, as Rodhe (1955 (33)) suggests for subarctic lakes in Sweden, becomes heterotrophic in the winter, using dissolved organic matter. Indeed, dissolved organic matter, in the form of leptopelic detritus, may play an important part in the direct diet of the young amphipods.

Acknowledgment

The author is indebted to Dr. E. H. Grainger, Arctic Unit, Fisheries Research Board of Canada, for a considerable proportion of the measurements of the *Themisto* material, and for the plotting and organization of some of them; also for the temperature data from the winter observations at Igloolik, Northwest Territories, 1955–56.

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Implications and assessments of environmental stress

INTRODUCTION

REE apparently unrelated questions on salmon have arisen in the past few years which, ıe face of inadequate knowledge, have taxed our judgement, produced considerable debate, sparked inquiry. In brief they are:

1) What is a *safe* level of water pollution for salmon?

2) What minimum level of oxygen concentration is required for normal development of on eggs?

3) Why is even a small loss of downstream migrants at a dam considered serious ı the Fraser River sockeye salmon is sustaining, on the average, an 80%* exploitation ıgh the action of the fishery?

ıe common denominator, of course, is that each of these questions relates to survival ome way, and survival is one measure of environmental stress. Thus, any consideration tress on individual fish, or populations in general, should shed some light on such lems, if not directly, at least indirectly.

o examine the questions further it is worth enlarging somewhat on how they arose and circumstances surrounding them.

TOXICITY TESTS

llowing a proposal for doubling the capacity of a kraft paper mill at the head of Alberni where the Somass River enters (see Waldichuk, 1954), we were asked to determine oxic level of the effluent for young salmon migrating through the area, so that appropri- lution or treatment of the outfall could be recommended. This we proceeded to do in standard fashion of bio-assays, involving determination of mortality curves, only we somewhat handicapped for working with unstable toxicants by the lack of appropriate

he 5-year period 1951 to 1955 the catch of sockeye was 78.9%, (see annual reports of the Inter- nal Pacific Salmon Fisheries Commission).

proportioning apparatus and were forced to use static volumes of diluted effluent, exchanging these every few hours. Since some of the toxic components (hydrogen sulphide) were highly volatile, no aeration could be used. Frequency of exchange was based on the rate of oxygen depletion in the closed containers; this called for setting a minimum "safe" level to which the oxygen could be depleted (through respiration and B.O.D.) before exchanging the solution. A second biological problem was consequently imposed on the prime bio-assay problem simply by the limitations of the experimental technique.

It was also necessary to select some level of salinity which could be considered representative of the environmental conditions which downstream migrants would encounter as they left the Somass River and entered the narrow inlet where the effluent was discharged. The question then arose as to the suitability of the cultured fish available in the laboratory in regard to their ability to meet an osmotic stress, relative to the ability of the natural-run fish. Finally, there was a question of an appropriate temperature and the acclimation state of the test fish.

Would an experiment under these laboratory conditions provide any sort of reasonable answer to the question at hand?

The results of the tests have been reported by Alderdice and Brett (1957). One of the interesting developments was the presence of certain side effects indicating sub-lethal respiratory stress. At the higher but non-lethal effluent concentrations a reduction in the fish's ability to extract oxygen had occurred (Fig. 1). It also appeared that there ability to be active was impaired, although experiments to confirm this suspicion were not conducted. Since these conditions were manifest at effluent concentrations which were not in themselves lethal, the problem of how to judge safe levels was obviously not being properly assessed by conducting bio-assays which depended upon estimates of mortality. How then could we hope to come to any conclusions by such an approach? Even if a critical level were determined (incipient mortality) what fraction of that level could be considered safe? Suffice it to say that the "safe" levels were finally set, not from mortality curves, but from observations on respiratory distress. The recommended concentration of not more than 2.5% effluent was approximately one-half that of the borderline lethal level. We have reason to suspect that even this may be too high.

TOLERANCE TO LOW OXYGEN

Experiments conducted to determine lethal levels of low oxygen during egg development revealed some rather remarkable relations (Alderice, Wickett and Brett, 1957). In the earliest stages (pregastrulation) chum salmon eggs could withstand very low saturations, of the order of one-tenth the concentration required by the time the embryo has reached an advanced stage. This transition, though progressive, showed greatest difference about the time free embryonic circulation was established. The extent of early resistance to hypoxia even suggests that anaerobic conditions might be withstood for some hours.

Two other phenomena accompanied the stress response to low oxygen. One was the production of deformities; the other a reduction in rate of development. Figure 2 illustrates the sort of disruption in somite formation which occurred when low oxygen concentrations were imposed from the twelfth to the nineteenth day after fertilization. It is as though the organization of the embryo was temporarily arrested at a particular stage, without loss of viability. The hatched alevins were apparently as active, in their inhibited way, as the normal stock, displaying rhythmic respiratory movements and heart pulsing with vitality. It is interesting that on one occasion the Nanaimo Biological Station received an oddly deformed adult salmon, picked up in the Sooke traps. This salmon was greatly truncated posterior to the dorsal fins, as though, like the deformed alevins, a few dozen somites had been left out!

In regard to retarded development, the criterion of delay was a significant increase in the

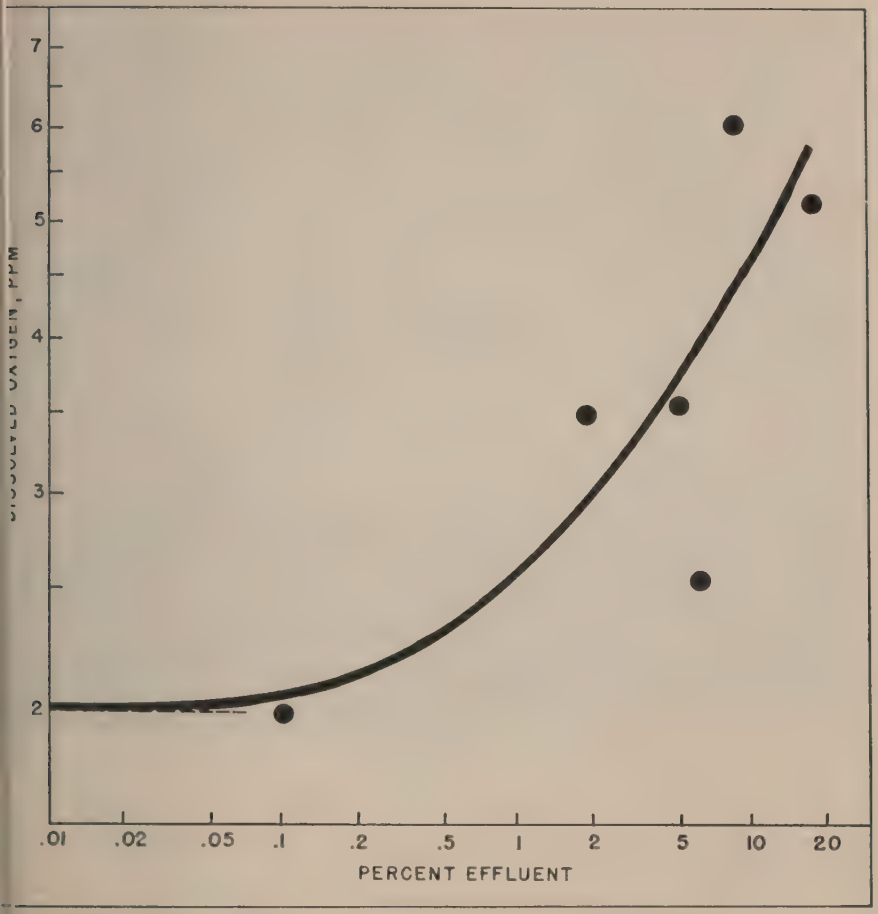

FIGURE 1.

RATION BETWEEN KRAFT MILL EFFLUENT CONCENTRATION AND LEVEL OF OXYGEN CON-TRATION AT WHICH RESPIRATORY DISTRESS WAS OBSERVED IN YOUNG SOCKEYE. Each point obtained by determining the concentration of oxygen at which fish first showed signs of distress respiring in a closed bottle containing a given concentration of effluent. The broken line indicates ow-oxygen lethal level (5% mortality) for young speckled trout (Shepard, 1955). From Alderdice Brett, 1957.

to hatching. In Figure 3 a three-dimensional graph prepared by Alderice (cf. Alderice, xett and Brett, 1957) illustrates the departure from normal hatching-time in relation to the degree of hypoxia (applied for a 7-day period) and the stage of development. magnitude of the "hump" in the graph, is indicative of the extent of stress as measured elay in hatching. A pronounced exception to this type response occurred late in develop-, at which time accelerated hatching resulted, portrayed in the graph by a "spur" in the r right-hand side. It could be interpreted as an effort on the part of the larva to break from the enclosing agg capsule with consequent increased freedom for respiration.

DOWNSTREAM MIGRANT LOSSES

vestigations of the losses of downstream migrants passing over a spill or through a turbine l anything from no apparent damage to highly lethal conditions according to the fe and height of the spillway, and the type of turbine (Hamilton and Andrew, 1954;

FIGURE 2.

DEFORMITY RESULTING FROM TEMPORARY EXPOSURE OF CHUM SALMON EGGS TO LOW OXYGEN CONCENTRATION AT AN EARLY INCUBATION STAGE, ILLUSTRATING THE MARKED TRUNCATION OF THE BODY POSTERIOR TO THE DORSAL FIN. (FROM: ALDERDICE, WICKETT AND BRETT, 1957).

Schoeneman and Junge, 1954). Recently the loss of young salmon passing through the 92-foot McNary Dam on the Columbia River has been documented (Anon., 1956) and an estimated 11% reported as killed by the turbines.

Let us assume for the minute that this 11% loss can be applied to the total stock of downstream migrants. As far as the fishery is concerned, the significance of this loss can only be truly assessed in terms of returning adults. It could be argued that since losses during the balance of ocean life are of the order of 90% of the downstream stock, that 9 out of every 10 fish were doomed by nature alone, and that such a *river* loss might be compensated, through decreased competition and increased ocean survival, to equal, say, only a 5% reduction in returning adults. Further, since a fishery like that on the Fraser can reduce the adult stock by 80%, yet the spawning and survival of young compensate for this unnatural loss, why should a reduction of only about one-eighth this amount at a young stage cause such concern? Perhaps by a slightly increased escapement the addition of an 11% turbine loss in the cycle could be written off.

Superficially there may appear to be some logic in this argument. However, the subject warrants much closer examination and can be approached through a consideration of the types of stress involved and the likely consequences of these very different factors, one a physical stress from impact and pressure change in the turbine, the other a biotic stress, comparable in many ways to population loss through predation.

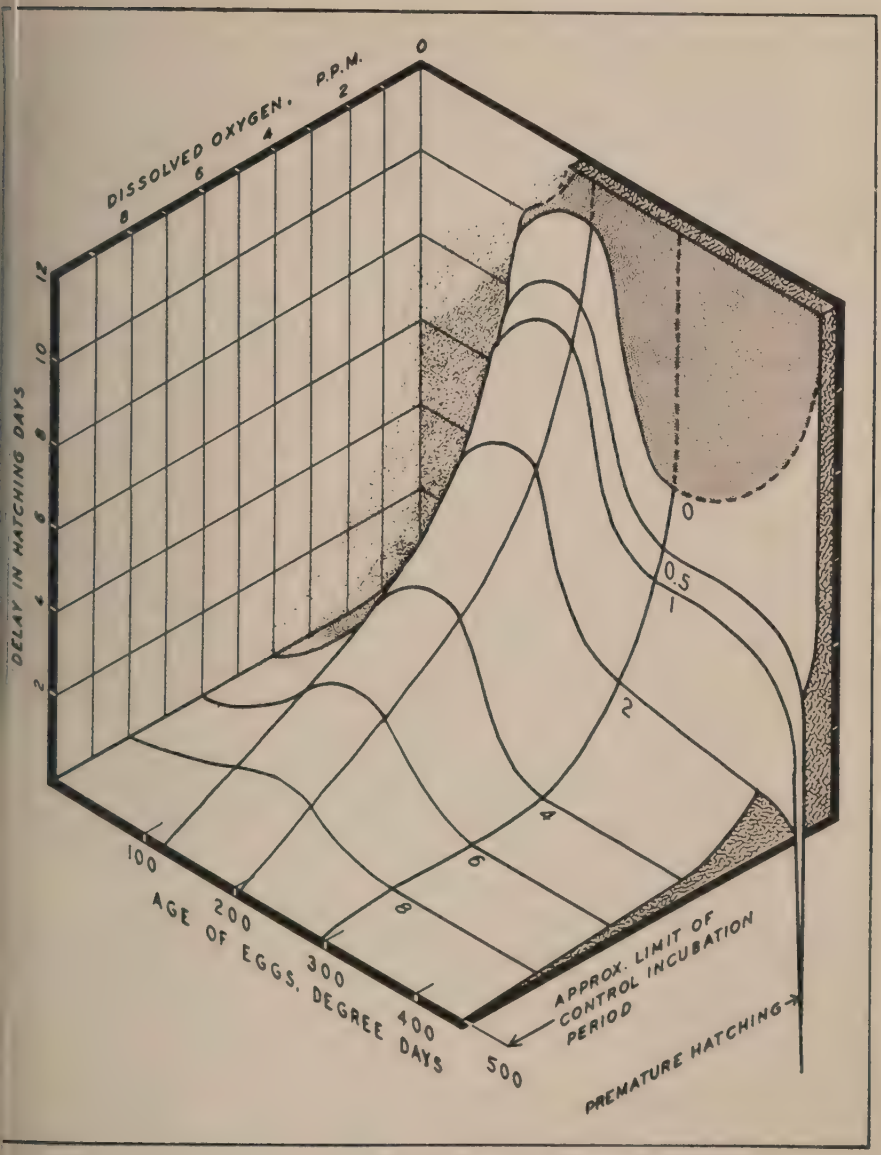

FIGURE 3.

LAY IN HATCHING IN CHUM SALMON EGGS RESULTING FROM A SEVEN-DAY EXPOSURE TO RIOUS LEVELS OF REDUCED OXYGEN CONCENTRATION. The stress of low oxygen was applied as a gle dose at a given stage of development. The severity of the stress is reflected by the magnitude of the mp". (From: Alderdice, Wickett and Brett, 1957).

STRESS, ITS DEFINITION

Before proceeding further on a discussion of stress, a clear definition must be established. m limited survey of the literature I cannot help but draw the tentative conclusion that body has attempted to define "stress" in terms which provide a good directive for biologists. medicine, Selye (1949, 1952) has given a specific definition for stated pathological umstances, and insofar as he has defined the term, has proceeded on an established basis.

This does not mean his definition has popular support, or should receive broader applicatior although there is a growing medical literature which has accepted his working hypothesis.

On the other hand, throughout biological literature, the word "stress" appears again an again, usually without any attempt by the authors to define it in any particular or speci sense. In the general content of these publications there is an inescapable implication of ex treme conditions, of an imposed load on an organism, of unavoidable though possibl temporary difficulty, of handicaps in some form or another, all of which call upon the an mal's reserves to make a major effort or suffer the consequences. In a general review endocrinology, Turner (1955) is somewhat more explicit in defining stress as "a harmf condition resulting from the inability of the organism to maintain an adequate intern equilibrium". Unfortunately, none of these allows one to measure stress as a quantity make estimates of the extent of severity, therby providing for a safe levels, if such exist. S it remains a descriptive word of qualitative value without precise biological interpretatio

Selye, however, by introducing a particular meaning has caused others to drop the wor from more general biological usage, or run the risk of doubt in the reader's mind as to ho the term is being applied. Selye's concept is perhaps most simply expressed in his 1952 publ cation where stress is defined as "a state of non-specific tension in living matter, which man fests itself by tangible morphologic changes in various organs and particularly in the endo rine glands which are under anterior pituitary control". The definition is one which was d veloped following considerable study of endocrine responses during induced pathologic states in mammals and natural occurrences in man. The most prominent morphologic and functional changes which occur are (1) enlargement of the adrenal cortex with a increase in the release of cortical steroids, (2) involution of the thymus and lymphatic organ (3) gastro-intestinal ulcers, and (4) variations in the resistance to stress. Collectively the constitute the General Adaptation Syndrome (G-A-S) which is manifest as a result of nor specific stress, such as severe chilling, burns, hemorrhage, anoxia, injury, or the initial stag of many diseases. Presumably the severity of the stress can be determined by the magnitud of the morphological and functional changes; also, in the *absence* of such indicators it mu be concluded that stress does not exist, at least in the defined sense.

It may develop that such symptoms can be used as a measure of the extent of stress in man animals. However, since they were observed in a study of mammals, strictly homoiotherm it is doubtful that such manifestations would characterize the thermal relations for poikilo therms; one could expect a variety of functional differences. It would seem desirable to see a more generalized proposition, yet one which provides for some form of quantitati expression.

At the risk of introducing a definition which might not bring the desired clarity to th concept of environmental stress, the following is proposed: stress is a state produced by an environmental or other factor which *extends* the adaptive responses of an animal beyond th normal range, or which distrubs the normal functioning to such an extent that, in either cas the chances of survival are significantly reduced. By this definition the magnitude of th stress then becomes possible of quantitative expression by an estimate of the chances survival (where actual losses can be recorded) or by a measure of reduction in capaci for normal performance.

ENVIRONMENTAL FACTORS PRODUCING STRESS

What they are:

Anybody who has been working with extremes of temperature, pressure, low levels oxygen, pollutants, fatigue, or disease has been working with stress in one form or anothe A long list of such stresses might be drawn up which could be enlarged as new items we

onceived. Systematically they could be grouped under appropriate headings according to heir nature as physical, chemical, or biological entities. Complexity would be introduced y choosing possible interacting factors, for instance the combined effects of raised tempera- ure, lowered salinity, and starvation with an added element of fatigue. This, after all, is xactly what adult salmon encounter when entering fresh water and migrating upstream, vith the further addition of a quota of parasites, the likelihood of infection, and the threat f predation, a net, or a gaff. Further classification might be added as in the manner f the action of toxicants by a consideration of cumulative stress involving *synergism* or *ntagonism*. This manner of categorizing undoubtedly has its place, however, it would seem nore effective for our purposes to think in terms of what a stress *does* or how it *acts*, rather han in the somewhat pigeon-holed form of "what it is". To take a functional approach is xactly what Fry (1947) did in a study of environmental factors and their effects on animal ctivity. Much can be learnt from this approach.

What they do:

At the outset a major distinction can be made between two types of stress, *discriminate* and *ndiscriminate*.

A *discriminate* stress is here defined as one which applies at any one time to individuals, *ngly* within a population and not to a group or stock as a whole. Thus, predation, extreme ndividual parasitism, acute localized disease, and injury or trauma can be considered dis- riminate stresses, exterminating or grossly affecting individuals without affecting the escaped" members. Predation can remove a significant segment of a maturing stock of salmon nd the balance proceed virtually unaffected to the spawning grounds. The status of the emainder may even be improved in some respects, if competition on spawning grounds has een reduced.

An *indiscriminate* stress is one which applies to every member and is not discrete in its ction. Stresses like high temperature, low oxygen or toxic effluents, spare no individual ntering or inhabiting an environment with such characteristics. There are, of course, differ- nces between individuals in their ability to resist a given stress, these resistances frequently eing normally distributed throughout the population. Thus, if an indiscriminate stress re- noves 50% of a uniformly exposed population, it means that the balance are suffering hough surviving, and that very little additional stress could have a catastrophic effect. Ability to continue normal activities will be impaired. Even a stress involving a small per- entage loss indicates that the balance of the population is under duress.

The status of the surviving members is the most significant difference, providing two ex- remes of condition as described.

The majority of biological stresses fall in the division of discriminate stress. With the xception of competition (producing malnutrition), mild disease or parasitism, they are sually lethal, or potentially lethal, reducing the capacity of the stricken individual to meet he balance of environmental stress (cf. Sheppe and Adams, 1957).

A word might be interjected here since *population pressure* and *population stress* could e confused. Population pressure appears to be confined to intraspecific competition (for ood, mates, spawning grounds etc.), whereas population stress applies to environmental actors in general including interspecific relations (e.g., predator-prey, parasite-host. See Nicholson, 1955). The type of stress arising from a population pressure such as food ompetition would be starvation or malnutrition, either in the short-rationed members or he population in general. Since the status of most individuals would be in jeopardy, opulation pressure can be considered to produce indiscriminate stress.

Physical and chemical stresses are almost invariably *indiscriminate*, and may act in a

variety of ways. The following categories appear desirable for appropriate distinction:

1. *Lethal.* The extreme effect of any stress is to destroy the organism. Bio-assays normally involve the determination of such levels. The terminology of Fry (1947) is applicable, in which the period of endurance prior to death is known as the *resistance time*, while the *incipient lethal* level denotes the boundary between *tolerance* and *resistance*. Temperature, radiation, pressure and toxicants are examples of potential lethal stresses.
2. *Limiting.* Here again Fry's concept is appropriate. These are factors which affect the supply of essential metabolites or interfere with the chain of energy release. Low oxygen may limit activity thereby providing a stress for an animal performing essential work. Insufficient substrates, nutrients and essential ions are other examples. These, of course, can reach the level of such short supply that death ensues.
3. *Inhibiting.* Inhibiting factors reduce the ability of the organism to carry out normal functions and, insofar as this introduces significantly lowered chances of survival, a stress is imposed. Narcotics, drugs, endocrine inactivation or imbalance, and depressors in general, fall in this category. Low temperature also affects poikilotherms as a metabolic inhibitor.
4. *Loading.* Any environmental factor which places an undue burden on an organism, necessitating the rapid or steady release of energy, invokes a stress. Abnormal osmotic pressure, high temperature and excessive muscular exertion can induce a *loading* stress.

Since temperature appears in three of these categories and my acquaintance with its effects on fish is greater than with other factors cited, some brief examples of stress from temperature will be considered.

Temperature as a *lethal* stress. Figure 4 is a typical thermal tolerance diagram for young salmon (cf. Brett, 1952). Around the periphery two lines have been drawn, one to depict the usual 50% or median tolerance limits, and the other for a 5% mortality level. It is significant that the difference between these two is relatively small, implying that temperatures of this order have only to increase slightly to cause a large difference in mortality. Outside the tolerance zone is therefore a high stress area, culminating in rapid death for young sockeye exposed to such extremes.

Temperature as a *loading* stress. The next enclosed area is fairly speculative and is introduced to portray a boundary for loading stress, beyond which activity in the form of swimming or growth would be seriously impaired. Growth in young sockeye tends to be poor to none-at-all at temperatures above and below 21°C. and 4°C. respectively (Donald and Foster, 1941); in addition swimming speeds are reduced by 40% to 60% of the overall optimum (Figure 5).

Temperature as an *inhibiting* stress. The smallest area is defined in its boundaries by temperature as an inhibiting stress, affecting normal endocrine balance necessary for spawning. This again is quite speculative and invites appropriate research to establish the boundaries and their full significance.

These various types of environmental stress are of major concern in establishing what sort of limits can be placed on the extent of change in fresh water which can be tolerated by salmon, without introducing stress at one stage or another.

One further example can be drawn from a consideration of a combination of stresses—*inhibiting* and *loading*. Maximum sustained cruising speeds of young sockeye in freshwater have been determined in our laboratory for fish acclimated over a range of 23°C. (Figure 5). They show an optimum speed at about 15°C. In this region the cruising speed is nearly three times that for a temperature approaching 0°C., and defines the level at which effective energy transformation is maximal. If a metabolic load is imposed, in

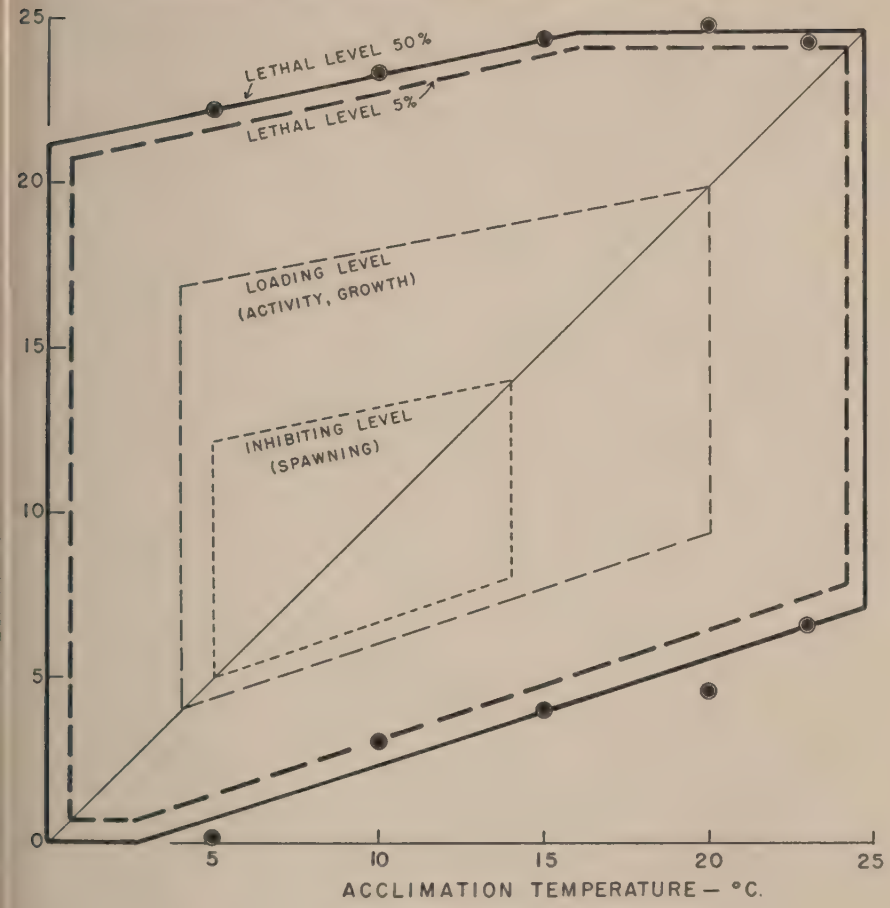

FIGURE 4.

NES OF TEMPERATURE TOLERANCE FOR YOUNG SOCKEYE SALMON. Lethal levels from Brett, 1952. ding and inhibiting levels yet to be determined, and merely suggested above.

njunction with an inhibiting factor, which in terms of energy demand equals that required swim at 0.5 ft./sec., the base-line can be raised as indicated in Figure 5. If we further agine that the fish are forced to swim at a rate of 0.5 ft./sec. to hold position in a stream r as adults, to move upstream), it is apparent that only between the temperatures of 13°C. l 17°C. is this achievement possible. Safety devices installed in rivers to protect young n from passing over spillways or through turbines, must take into account the problems sed by the combined effects of environmental stress.

THE ASSESSMENT OF ENVIRONMENTAL STRESS

In a review of physiological variation in animals, Prosser (1955) has pointed out some the essential differences in the way animals meet the problem of environmental stress. o extreme ways of adapting exist. The first is through physiological *adjustment* in which internal state changes with environmental change. This is the case for fish in regard body temperature, involving the process of thermal acclimation. The second is by ysiological *regulation*, whereby a relatively constant internal state is maintained despite nsiderable environmental change (homoeostasis). Control of pH, salinity, blood-sugar l gas content are examples of regulated internal states in fish. Figure 6 is adapted from

Prosser's paper and shows the relative manner in which adjustors and regulators respon to environmental stress. The broken lines indicate where adaptation fails and survival time is limited, a region of extreme stress.

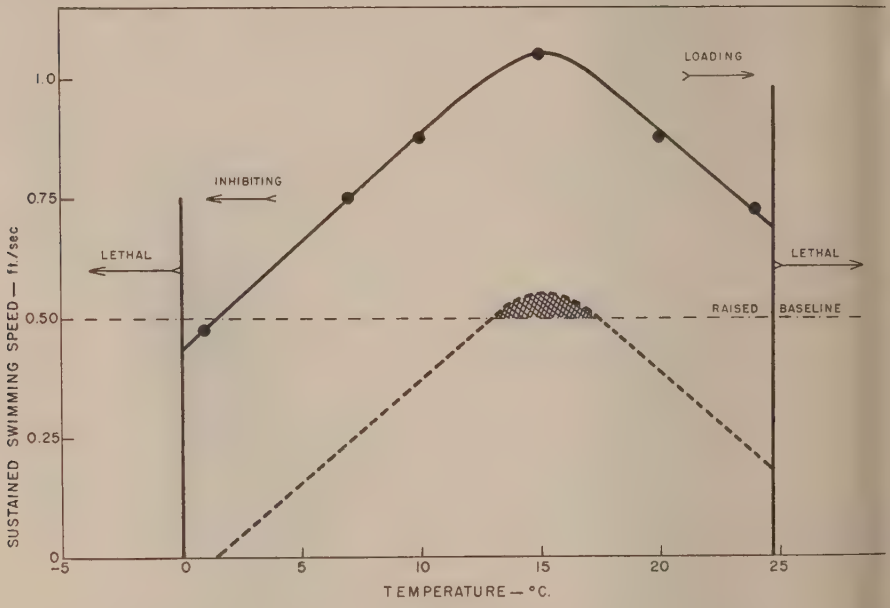

FIGURE 5.

RELATION BETWEEN PERFORMANCE (SWIMMING SPEED) AND TEMPERATURE FOR ACCLIMATE YOUNG SOCKEYE SALMON. The dotted curve represents the remaining "energy" (i.e., capacity to swim when stemming a current of 0.5 ft./sec. The raised base-line has been elevated by an amount equal to th energy demand of swimming at 0.5 ft./sec. and represents an assumed increment from imposed multipl stress. Only in the cross-hatched area could young salmon meet this situation. (Adapted from Brett, 1957)

Such mechanisms as internal regulation, adjustment, acclimation, and even hibernatio aestivation and migration appear to be methods by which animals have overcome th problem of environmental stress and managed to survive. Insofar as environmental change do not *extend* adaptive powers, then it is the thesis set forth here that stress does not exist and that such responses are simply a part of normal living. Excitation is therefore not stress unless (for instance) it becomes a loading factor, or causes an imbalance in hormona secretion. Light is a good example. Increasing day-length can stimulate gonad maturatio in an orderly series of adaptive responses. At the same time, the daily rise and fall i light intensity is accompanied by adaptive responses of the iris and movement of the visua cells. However, extremes can cause injury resulting in inflammation, or night-blindness This falls in the category of an indiscriminate stress from radiation causing sub-letha trauma. Rasquin and Rosenbloom (1954) have made a detailed study of endocrin imbalance in teleosts when maintained in complete darkness. A remarkable number o metabolic disturbances occurred, including growth changes, calcium loss, kidney degenera tion, and subsequent atrophy of the thyroid and interrenal glands. The authors state tha "Living in darkness can be considered a situation of long-continued stress that could b overcome if the fish were returned to light after four months in darkness but that resulte in the death of 16 of 19 fish returned to light after over a year in darkness."

In most instances starvation would be considered a stress, yet salmon must be internally geared to survive a relatively long period of starvation prior to spawning. If Selye

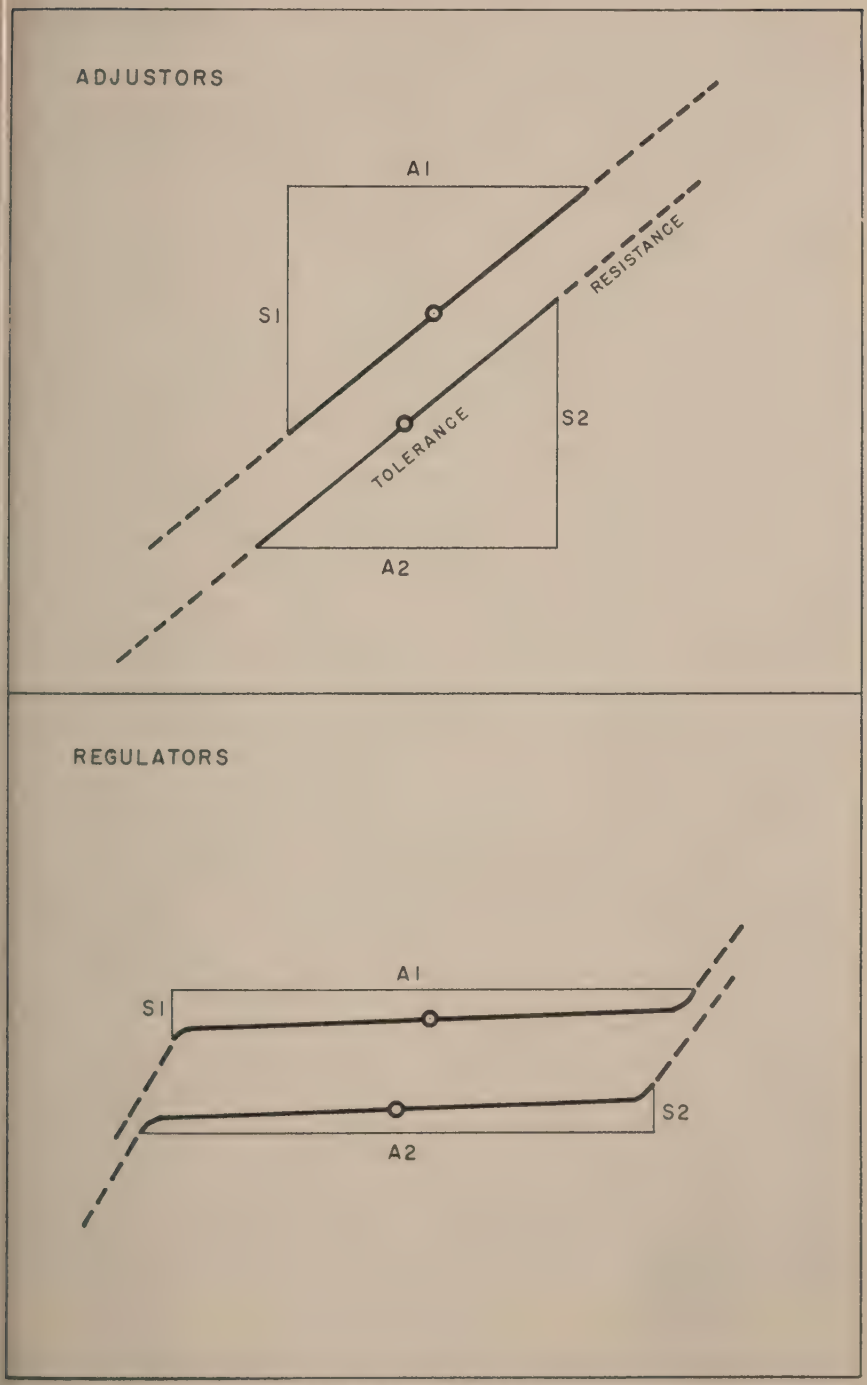

FIGURE 6.

GRAMMATIC ILLUSTRATION OF THE RELATION BETWEEN INTERNAL STATE AND EXTERNAL ESS FOR PHYSIOLOGICAL ADJUSTORS AND REGULATORS, AT TWO LEVELS OF ACCLIMATION AND A_2). Note the difference in change of internal states (S_1 and S_2) for the two types. (From sset, 1955).

criteria of stress were applied it seems most unlikely that disruptive endocrine imbalan would be present if normal maturation proceeds, and hence no internal stress. Yet t culmination for Pacific salmon is death. Final imbalances must take over.

The assessment of stress cannot involve simply the determination of change, any chan induced in the internal state of an animal. Homoeostasis does not really mean a stea state, but rather a continual return to a mean level, involving oscillations of relatively sm magnitude. Turner (1955) states, "ordinarily, if the stimuli are not too severe, adaptatic go on quietly as a part of general life processes and no harmful homoeostatic imbalanc prevail. On the other hand, the damaging agent may be of such intensity or duration tl homoeostasis is not achieved and biologic harm results". Criteria of stress then should related to changes which imply the presence of one or other of the types of stress postulated lethal, limiting, inhibiting and loading. There is a physiological criterion, readily measure which is common to each of these, namely *metabolic level*. No matter what environmen stress is placed on an animal it will, almost invariably, be reflected in a change (increa or decrease) in normal metabolic rates. Herein lies the key to the assessment of enviro mental stress, whether discriminate or indiscriminate. Zero metabolism of course refle death, the culmination of lethal stress. Critical, pre-lethal states will be accompanied great depression in metabolism, as in near low-lethal temperatures, or by extreme heigl of metabolism when temperature approaches the upper lethal level. Reduced metaboli may result from a limiting or inhibiting stress. A loading stress is accompanied by i creased metabolism. It is desirable to define whether active or standard metabolism affected, but since the difference between these two is reflected in performance capaci (Fry 1947), an alternative to metabolic measurement is supplied by determining the exte to which normal performance is reduced. This is particularly appropriate to the proble of assessing environmental stress. Metabolic measurements are frequently performed by tl use of respirometers or by the nature and level of nitrogen excretion. Two points aris The first is the need for establishing norms for the metabolic levels which accompany wide variety of normal functions and activities in fish. The second is the decision regar ing the degree of change which must occur before stress can be considered to be preser from which an estimate of the extent of stress can be assigned. It would seem that th boundary between normal function and the onset of stress must remain arbitrary in pa since the determining of a significant decrease in chances of survival is not a simple matte nor can it be ascertained in short order. However, it may be possible to derive some bas from the limits of normal distribution of animals. Prosser *et al.* (1950) comment that tl "explanation of both restricted and widely diversified distribution can be obtained l examining physiological reactions to environmental stress". Speckled trout, for instanc are rarely found above 19°C., yet they can tolerate 25°C. The metabolic level 19°C. may well be on the survival fringe, beyond which the temperature load becomes a stres In addition, metabolic levels might be correlated with internal changes such as those record by Rasquin and Rosenbloom (loc. cit.) or those by Selye (loc. cit.) in the Gener Adaptation Syndrome. There is room for a great deal of fundamental research at this stag inviting one's imagination.

IMPLICATION FOR SALMON

The implications for salmon from hydro-electric power development are, almost in eve case, those of increasing stress. Attention should not, however, be focussed entirely on tl dams. They form a part of a total problem, the problem of adult salmon reaching spawnir grounds in fit condition, and of downstream migrants entering the ocean as active, healtl young fish. Maturing salmon arriving at the base of a dam may already have been expose

a variety of stresses arising out of downstream pollution, abnormally high temperatures n poor run-off, delay in entry, or even a period of poor growth in the ocean. The dam its effects must be considered in relation to the particular status of the fish. More than environmental blow may have been dealt by this stage. The stress imposed by a dam st, therefore, be considered in terms of the problem of *total* environmental stress.

We may now return to a consideration of the questions posed at the start of this discussion.

ic Levels:

n the toxicity tests, involving indiscriminate stress, it was apparent that a lethal ponent was present at concentrations of the order of 4.8 per cent effluent and above. wever, either a loading stress or an inhibiting stress (determined by whether metabolism p or down) caused respiratory distress, requiring an increased oxygen tension for relief. earlier comments ended with a note of doubt as to whether even the lower level of 2.5 cent effluent could be considered safe, that is, not imposing a stress beyond the limits normal adaptive response. There is considerable likelihood that the minimum oxygen ion designated as required would be found to be at the level of a limiting stress if ormance were tested. The polluted area is one through which adult salmon must make r way to arrive at spawning grounds, in a river system, by the way, which appears ined for considerable hydro-electric development.

here is added reason to be most cautious about the level of pollution which should be nitted in Alberni Inlet.

vnstream Migrants:

a significant feature of stress applied to downstream migrants by passage through a bine is that it is likely to be indiscriminate. This is a fundamental difference between ss at a dam, and a loss from a fishery. The stress of a fishery is discriminate. With the ption of a fringe group which have sustained some injury, the survivors are not reciably impaired. A diametrically opposite state exists for an indiscriminate stress. The sure changes experienced by the total number of fish passing through a turbine are ially uniform; differences in survival are simply according to the distribution of stance within the population. Any lethal stress which has reached the stage of rminating 10% is approaching the catastrophic level. Slight changes, small additional ses, can mean total loss, just as in the temperature-stress chart (Figure 4), where only nall margin exists between the 5% and 50% mortality levels.

n the case of McNary Dam, there is some suggestion that the particular 11% loss through turbines did not place the surviving balance of the population at the brink of death. same percentage loss was estimated from samples taken at stations distributed over 150 s downstream. If the damage were entirely from the rapid change of pressure one ld expect some increase in percentage mortality between the near-dam and far-dam pling sites, if only from relatively increased predation on pressure-impaired survivors e no such loss was recorded and assuming that this case is representative, we can deduce the turbine stress is not uniform but is discriminate; that at least part of the stress is ctive in some way. One would be led to suspect that impact from the runners, or lized cavitation was providing a second stress roughly at the 10% population level.

CONCLUSION

he thesis is presented that a working definition of stress is a state produced by any ronmental factor which extends the normal adaptive responses of an animal, or which urbs the normal functioning to such an extent that the chances of survival are significantly ced.

wo major subdivisions of stress can be distinguished, discriminate and indiscriminate

The chief distinction separating these two is in the status of the surviving individuals.

Discriminate stress is measured simply by the percentage loss, being strictly a leth stress not inflicting any particular handicap on the balance of the assailed population. Loss from predation or from a fishery fall in this category, which is the reason why a populatic such as the sockeye of the Fraser River can withstand an 80% loss, yet reproduce at sustained high level.

For indiscriminate stress, four categories appear to embrace most of the conditions und which this form of stress acts, viz., lethal, limiting, inhibiting and loading. Either l direct loss or through measures of metabolism reflecting reduced performance, a measure the stress can be ascertained. Since altered water conditions are likely to cause indiscrimin stress, any loss from hydro-electric or other industrial development can be consider suspect for serious consequences to the total population.

The establishing of norms is one of the prime research responsibilities, from which estimate of stress may be derived, and the safe limits of environmental change determin The tasks are many and inviting. The examination of stress and how it operates shou provide greater insight in the investigation of fish-power problems.

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DISCUSSION

DR. LARKIN: Would you care to comment on the possibilities that indiscriminate stresses m occur even when no mortality is evident?

DR. BRETT: The distinction between discriminate and indiscriminate stress is valuable. It h allowed us a few fresh approaches in the problem of determining experimentally wh changes may be possible in fresh water without serious effects on salmon. For instan

where there is a general rise in river temperature from damming, and fish are being delivered above a dam without loss, it must be remembered that the fish still have to pass through the reservoir and proceed to spawning grounds. The question for adult salmon is not just a case of surviving to the top of the ladder but of reaching spawning grounds in a healthy condition. How to tell if the fish has the capacity to meet the total stress is the question to be answered.

Another example can be taken where young fish have passed through a turbine or over a spill and no mortality is observed. This does not mean of course that no stress exists, or that the fish are not temporarily or permanently handicapped in some way. The final test is whether a normal number of adults return despite the pressure changes or impact imposed on the young stage. It should be possible to determine the handicap by appropriate tests and examination in the laboratory through a study of metabolism and performance and thereby determine the sublethal stress.

VERHOEVEN: Dr. Brett said something earlier that put a certain form of stress on me. I wish to take exception to it and that was the suggestion that the loss through indiscriminate stress could be made up by a slight decrease in the fisheries take. No comment was made on the accumulation of stress. On the Columbia River their exploitation is already in the range of sixty to eighty per cent. We are already restricting the catch to a limit.

BRETT: I quite agree with Dr. Verhoeven, and perhaps did not make myself clear. I was trying to show that, if you have a loss of 10% from indiscriminate stress it is likely to make a considerable difference on subsequent survival. Whereas, if you have a discriminate stress of the order of even 80%, the balance of the population of egg-carrying adults is likely to be unaffected. The conclusion is: Watch out even if you have only got a low percentage mortality from a dam.

PRITCHARD: Taking the proposed dams on the Columbia River and assuming this 11% loss for each dam proposed on the main stem, for the sockeye migration emerging from the Okanagan and passing through the nine dams on the Columbia River, of one million leaving the Okanagan, only 35 would reach salt water.

BRETT: I think not even 35! The accumulation of indiscriminate stress from pressure is likely to be very severe.

THOMPSON: My interest in your own work (Dr. Black's) on the effect of activity on the salmon arose from concern of effects of tagging, and the failure of fish which had been tagged (after struggling in the net) to return. Our interest therefore goes beyond the problem of immediate death of these animals. When they are tagged they are dropped overboard and have to maintain at the surface or sink into the depths and die. It isn't merely the lethal effect of activity, it is probably the function of the organism as a whole. In other words, the capacity to maintain normal activity in an environment. So I hope your experiments will go further than "life and death" and cover organism activity and survival. I suggest you broaden your activity in that field.

BLACK: I hope in the near future to combine with Dr. Brett in his analysis of problems of stress and fatigue.

[Reprinted from Food Technology, 1958, Vol. 12, No. 1, Pages 44-48]

Predicting the Color of Canned Sockeye Salmon from the Color of the Raw Flesh

(Manuscript received July 30, 1957)

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As is the case with many other food products, the color of canned salmon is a very important quality factor *(5)*. Most salmon flesh contains red carotenoid pigments *(2)* which lend an attractive color to the canned products. In this country, Government requirements for color must be met only for canned spring salmon *(Oncorhynchus tschawytscha) (4)*. Specifications for red, pink, and white canned spring salmon have been defined in terms of Lovibond-Schofield red units *(14)*. There are no official color standards for the other four species of canned salmon. However, the salmon canneries generally color grade all products each to their own standards. Unfortunately, the color grade must be predicted prior to canning. This has presented a problem which industry has attempted to minimize by canning separately fish from areas known to have lower color quality and also by visual grading of the raw fish. Such visual grading is done without material standards for comparison. Although the Lovibond-Schofield instrument is suitable for inspection purposes, it is not used for the commercial grading of salmon. The color of the various grades of canned salmon have not been sufficiently uniform, indicating that more accurate methods of specification and prediction of the color are needed.

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Precise color specifications would be useful both for grading purposes and for the establishment of regulatory standards.

For the present study, an accurate objective method of color measurement was necessary. Charnley *(5)* and Charnley and Bolton *(6)* made color measurements of canned salmon using a modified Lovibond Tintometer to study the relationship between red and yellow color units. In recent years photoelectric instruments have been utilized for the measurement of the color of various food products. The Hunter Color-Difference Meter has had successful application in color studies on tomatoes *(3, 16)*, tomato juice *(11, 12)* and strawberries *(15)*. The Gardner Automatic Color-Difference Meter *(1)*, which is an automatic model of the Hunter Color-Difference Meter, was used in this investigation.

Of the 5 species of Pacific salmon, sockeye *(Oncorhynchus nerka)* was selected for study because it has the greatest commercial value in this area. This project was undertaken to determine a basis for indicating the visual color preference for canned sockeye salmon and to ascertain the feasibility of predicting the color of canned sockeye salmon from the color of the raw flesh. Other aspects included in this study were: (a) a comparison between color measurements of raw and canned salmon made with the Beckman DU spectrophotometer, the Lovibond-Schofield Tintometer, and the Gardner Color-Difference Meter; (b) the correlation between the oil content and color of canned sockeye salmon; (c) the effect of increased temperature and time of processing on the color of the canned product; (d) the effect of *post-mortem* storage on the color of canned salmon.

PROCEDURE AND MATERIALS

Spectrophotometric measurements. Directional reflectance measurements were made using a Model DU Beckman Spectrophotometer equipped with a reflectance attachment and a "photomultiplier" tube. A white vitrolite block calibrated against 2 different $MgCO_3$ blocks was used as a reference standard. Measurements were taken at 10 mμ intervals from 400 to 750 mμ and the slit width was never allowed to exceed 0.15 mm. The I.C.I. (International Commission on Illumination) tristimulus values for illuminant C were calculated by

the summation method *(10)*. The large-scale chromaticity charts of Hardy *(8)* were used to obtain the dominant wavelength and per cent excitation purity.

Color-Difference Meter measurements. The Gardner Automatic Color-Difference Meter was used for these measurements. This instrument is the same as the Hunter Color-Difference Meter, except that its measuring circuit has been changed to include motor-driven potentiometers for speed and ease of operation. The *Rd* scale and large area illumination without a cover plate were used throughout. The instrument was adjusted to give the reading of the reference standard before each sample was measured. For the raw samples, the average of triplicate measurements of *Rd*, *a* and *b* were taken, the sample being turned twice after the initial measurement. Single readings of *Rd*, *a* and *b* were sufficient for the canned samples because of the excellent reproducibility of these measurements. The reference standards were 2 colored porcelain-on-steel tiles manufactured especially for this study and calibrated using the Beckman spectrophotometer, which was checked with standards supplied by the Gardner Company. The *Rd*, *a* and *b* values were calculated from the tristimulus values using the appropriate equations *(9)*. The reference tile used with the raw samples had *Rd*, *a* and *b* readings of 8.73, 33.8 and 20.7 respectively, while that used with canned samples had values of 35.9, 15.4 and 24.1, respectively. The reflectance curves of these 2 tiles were similar to those of raw and canned sockeye salmon as shown in Figure 1.

The Lovibond-Schofield Tintometer. This is a visual subtractive colorimeter using Lovibond glass filters like the Lovibond Tintometer but having an auxiliary device for controlling the luminance of the comparison field. Color measurements can thus be made using only 2 of the 3 series of color slides. Conversion graphs are provided so that the readings can be converted to the I.C.I. system. A $MgCO_3$ block was used as a reference standard and a liquid filter served to provide illuminant C. The average of two measurements made on each sample was used.

Preparation of samples. A half-lb. steak was cut from the section just forward of the dorsal fin of each raw fish. For the Color-Difference Meter and Lovibond-Schofield measurements, a small bone-free and skin-free sample was placed in a dish 3 inches in diameter and one-half inch in depth and was smoothed with a blade. For the spectrophotometric measurements the sample was reduced in size to fit a one and one-half inch diameter dish. After taking the color measurements, the sample together with the steak from which it was cut, was placed in a half-lb. salmon tin, vacuum closed and processed at 116° C. for 90 minutes. To make color measurements of the processed fish, the skin, bones and curd were removed and the remaining flesh and liquor were thoroughly mixed with a spoon. Samples were then placed in the dishes, smoothed with a blade and the color measurements taken.

Determination of oil content. The oil content of the canned samples was determined by a method developed especially for

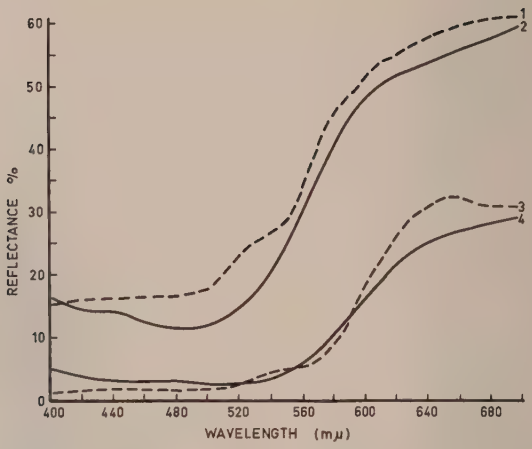

Figure 1. Reflectance curves for (1) reference tile for canned salmon measurements; (2) canned salmon; (3) reference tile for raw salmon measurements; (4) raw salmon.

this purpose *(13)*. This method, which was more rapid than standard procedures, was employed because of the large number of samples (416) analyzed. To determine the oil content by this procedure the sample of canned salmon is minced in a Waring blender. Ten grams of the sample are weighed into a 100-ml. volumetric flask. Forty ml. of acetone and some boiling chips are added and the mixture is refluxed for one hour. Thirty-five ml. of methylene chloride are then added and the refluxing is continued for an additional 30 minutes. The solution is then cooled to 25° C., made up to volume with methylene chloride and shaken. It is filtered through glass wool and 50 ml. of the filtrate is measured into a 100-ml. tared beaker. The solvent is evaporated on a steam bath and later in a vacuum oven at 100° C. for 1 hour. After cooling, the beaker is weighed and the per cent oil is calculated from the formula, % oil = (wt. of oil/wt. of sample) × 186. This method has been compared with established procedures and the results will be published elsewhere.

RESULTS AND DISCUSSION

Comparison of 3 color-measuring instruments. Seven samples of both the raw and processed fish were subjected to color measurement using the Beckman DU spectrophotometer, the Lovibond-Schofield Tintometer and the Gardner Color-Difference Meter. These measurements were converted to I.C.I. dominant wavelength and per cent excitation purity and

are recorded in Table 1. The 3 instruments did not give identical results. Such discrepancies have been observed by other investigators working with different products *(7, 11, 15)*. Agreement between the spectrophotometer and Color-Difference Meter was better than between the spectrophotometer and Lovibond-Schofield Tintometer. Because of the long period of time required for the spectrophotometric measurements, considerable darkening of the sample surface occurred before the measurements were completed and may account for some of the discrepancies. Agreement between instruments was better for processed samples than for raw samples. This is not surprising because the reproducibility of measurements with a given instrument was found to be much better for the processed samples, and may be attributed to the fact that the raw samples were not so uniform in color, had an irregular surface texture and a slight translucency. The Color-Difference Meter has several advantages over the other two instruments for these measurements. Because of the nature of the raw samples, more accurate results can be obtained with an instrument viewing a larger sample area as does the Color Difference Meter. In addition, this instrument is much more convenient and more rapid than either of the other two.

Color measurements of raw and processed sockeye salmon. Typical reflectance spectra of a sample before and after processing are shown in Figure 1. Processing increased the brightness throughout the entire visible region, particularly above 560 mμ.

Color-Difference Meter data were obtained on samples from 416 individual freshly-caught sockeye salmon before and after canning. The fish were caught in 8 different areas and at various times during the 1956 season. The *Rd*, *a* and *b* readings for 60 of these samples were selected to contain approximately the whole range of colors, were converted to I.C.I. trichromatic values and then to dominant wavelength and per cent excitation purity. Extensive changes occurred in each of the 3 color dimensions during the cooking process (Table 2). The samples became much lighter while the hue was shifted from red to orange-red and orange and the purity decreased.

TABLE 1

Comparison of instruments for color measurement

Sample No.	Spectrophotometer			Color-Difference Meter			Lovibond Schofield		
	Y, %	Dominant wave-length mμ	Purity %	Y, %	Dominant wave-length mμ	Purity %	Y, %	Dominant wave-length mμ	Purity %
Raw Sockeye Salmon									
1	8.39	603.6	56.0	9.0	602.3	71.2	11.5	604.7	70.5
2	9.97	598.2	58.3	12.2	598.9	66.5	11.8	603.0	66.0
3	10.6	599.0	57.5	11.5	600.0	69.7	14.5	599.7	70.5
4	10.0	598.7	57.5	11.5	600.1	68.0	12.3	601.7	70.4
5	12.1	595.6	54.0	14.0	596.8	64.2	16.6	599.4	59.1
6	9.96	600.0	58.0	12.1	600.1	68.0	12.9	600.5	73.2
7	10.7	600.0	63.3	13.2	600.2	68.4	14.5	602.0	67.4
Processed Sockeye Salmon									
1	30.3	590.0	49.4	34.9	588.9	50.3	48.0	590.1	48.3
2	35.9	588.6	43.6	38.6	587.4	43.6	41.7	589.7	44.3
3	35.2	589.8	48.3	39.6	589.1	49.3	40.7	590.4	47.3
4	33.6	589.3	50.0	37.8	589.0	48.1	40.7	590.8	46.2
5	36.2	587.6	43.0	40.8	586.3	41.5	43.7	589.2	38.7
6	32.2	589.5	50.2	36.5	588.5	47.9	33.1	590.0	45.6
7	30.6	590.0	48.0	33.9	588.8	48.2	33.9	591.2	44.6

Color measurements of canned salmon. The *a* readings ranged from 7.1 to 29.8 and had an average value of 19.9 while the *b* readings varied from 19.5 to 26.9. There was excellent correlation between the *a*/*b* ratio and the dominant wavelength. However, there was very good agreement between the dominant wavelength and the *a* value alone, the linear correlation coefficient being 0.991 for the 60 samples previously mentioned. In addition, the *a* value was found to

TABLE 2

Range of colors from converted color-difference meter measurements of 60 samples of sockeye salmon before and after processing

Color attribute	Range	
	Raw	Processed
Lightness, %	9.00– 21.1	28.6– 52.5
Dominent Wavelength, mμ	591.0 –602.3	582.3–592.2
Purity, %	41.7 – 73.3	29.1– 60.0

correlate well with purity and lightness, the correlation coefficients being 0.943 and −0.834, respectively. This meant that with an increase in *a* value, there was an increase in dominant wavelength, purity and darkness. During the course of these measurements it became evident that the *a* readings were a good measure of visual color preference. A panel of qualified representatives from the salmon canning industry and from the Canadian Government Canned Fish Inspection Laboratory were consulted to make visual color judgments of approximately 100 samples of canned sockeye salmon. Their evaluations showed that the higher the *a* value the more preferable was the color of the product. In collaboration with this panel it was concluded that there should be 3 commercial color grades of sockeye salmon with specifications defined in terms of *a* values as follows: grade 1, the best grade, shoul have *a* values greater than 20; grade 2 should have *a* values not greater than 20 and not less than 14.5, while grade 3 should have *a* values less than 14.5. On the basis of these specifications, Table 3 lists the percentage of fish that were grades 1, 2 and 3 when canned from each of the 8 areas where the salmon were caught. These data show that in

general the sockeye salmon from the more southerly areas had a better color. Only the Rivers Inlet area contributed any appreciable number of grade 3 canned salmon. Particular difficulty in color grading sockeye salmon from this area has been experienced by the industry.

Prediction of a value of canned salmon. The problem of grading was thus reduced to predicting the *a* value of the canned product from the color of the raw fish. The *a* readings of the raw samples had an average value of 34.7 and ranged from 16.8 to 43.3, while the *b* readings ranged from 14.9 to 25.8 with most of the readings falling between 18 and 23. As with the canned samples, the *a/b* ratio was found to be directly proportional to the dominant wavelength.

TABLE 3

Percentage of sockeye salmon from different areas in each color grade

Area of capture	No. of fish	% of fish in each grade when canned		
		Grade 1	Grade 2	Grade 3
West coast of Vancouver Island	40	70.0	30.0	0
Fraser River	79	73.4	25.3	1.3
Rivers Inlet	95	22.1	53.7	24.2
Juan de Fuca	78	44.9	55.1	0
Johnstone Strait	57	61.4	36.9	1.7
Bella Coola	37	54.1	43.2	2.7
Pender Harbour	10	80.0	20.0	0
Fitzhugh Sound	20	35.0	65.0	0
All areas	416	51.0	42.8	6.2

Linear correlation coefficients between the *a* values of the canned samples and the *a*, *a/b* and *Rd* values of the raw samples were as follows: $a = 0.637$; $a/b = 0.787$; $Rd = -0.170$. Regression equations for predicting the *a* value of the canned salmon from either the *a* or *a/b* value of the raw fish were as follows: $a_c = 0.550\ a_r + 0.786$ and $a_c = 18.479\ (a/b)_r - 10.801$, where the sub-letters *c* and *r* refer to canned and raw sample readings, respectively. The standard errors of estimate were 2.72 *a* units for the first equation and 2.18 for the second. From the visual color evaluations made by the panel members mentioned earlier, the permissible grade tolerances for canned salmon were estimated to be $\pm$ 1 *a* unit. This meant that *a* values as low as 19 for grade 1 and as high as

15.5 for grade 3 were permissible, whereas the a values for grade 2 could extend from 13.5 to 21.0. On the basis of the above specifications, the a value separating grade 1 and 2 canned salmon was 20, while that separating grade 2 and 3 was 14.5. From the second regression equation, the a/b ratios for the raw fish corresponding to these a values were calculated to be 1.67 and 1.37, as shown graphically in Figure 2. Grade specifications in terms of a/b ratios for raw fish can be stated thus: grade 1 — a/b value must exceed 1.67; grade 2 — a/b value must exceed 1.37 but must be less than 1.67; grade 3 — a/b value must be less than 1.37. When the 416 samples were graded on their a/b ratios it was found that 37 samples or 8.9% fell in the incorrect grade on the basis of the a value specifications and the limits outlined earlier for the canned fish. Of the incorrectly graded samples 15 of them with an average a value of 17.5 were placed in grade 1 instead of grade 2, 18 samples with an average a value of 21.9 were placed in grade 2 instead of grade 1, 4 samples with an average a value of 12.9 were in grade 2 instead of grade 3, and only 1 sample was incorrectly placed in grade 3. The samples that were incorrectly graded were not from any particular area nor of any particular period of the season. The average a value of the canned samples placed in each of the 3 grades was as follows: grade 1 — 21.0; grade 2 — 19.0; grade 3 — 11.2. The per cent of fish in grades 1, 2 and 3 now was 56.9, 39.7 and 3.4 respectively. When a similar grading procedure was applied using the a values of the raw fish rather than the a/b ratios, 12.5% of the samples were incorrectly graded. This method failed particularly in correctly placing the grade 3 samples. These results indicated that the color grade of canned sockeye salmon could best be predicted from the a/b ratio of the raw fish and that the prediction within specified limits was 91% accurate.

If visual grading, based on these specifications, were desirable, at least 2 material reference standards would be required, one having an a/b ratio of 1.67 and the other having a ratio of 1.37. The a values of 20.0 and 14.5 for canned fish were applied to the first regression equation to give the best a values for such

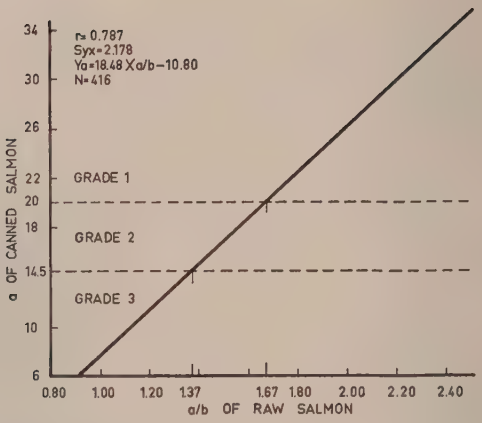

Figure 2. Regression line for estimating a readings of canned sockeye salmon.

reference standards, namely 34.9 and 24.9. To retain the correct a/b ratios, the b values were calculated to be 20.9 and 18.2 respectively. The average Rd values for 76 raw samples whose a/b ratios varied from 1.65 to 1.69 was 12.9 while that for 23 samples with a/b ratios ranging from 1.30 to 1.45 was 14.1. Thus the complete specifications for such reference standards are: (a) $Rd = 12.9$, $a = 34.9$, $b = 20.9$; (b) $Rd = 14.1$, $a = 24.9$, $b = 18.2$. Visual grading utilizing standards with such specifications is currently under investigation. Color grading by means of an automatic photoelectric method measuring a/b ratios of the raw fish would of course be more satisfactory. However, the commercial application of such a method will require further experimentation.

Relationship of oil content to color. The oil content of each of the 416 cans of processed sockeye salmon was determined. The data in Table 4 show that in general the more desirable color grades of sockeye salmon had a slightly higher oil content. However, on an area basis this was not always true. For example, Juan de Fuca samples had a higher average oil content (14.9%), but a lower average a value than the samples from 4 other areas. For a given area the grade 1 samples had a higher average oil content than

TABLE 4

Average a readings and average oil contents of sockeye salmon of 3 different color grades from 8 different areas

Area	No. of fish	Average oil content			Average *a* reading	Average oil content
		Grade 1	Grade 2	Grade 3		
West coast of Vancouver Is.	40	10.5	9.39	None	21.1	10.1
Fraser River	79	12.3	11.4	9.39	21.4	12.0
Rivers Inlet	95	9.58	9.67	9.48	17.0	9.58
Juan de Fuca	78	15.5	14.4	None	20.4	14.9
Johnstone Strait	57	12.4	12.3	11.5	21.2	12.4
Bella Coola	37	9.86	8.97	2.19	19.2	9.28
Pender Harbour	10	9.39	10.8	None	21.5	9.67
Fitzhugh Sound	20	9.00	7.18	None	19.6	7.82
All areas	416	11.9	11.1	9.28	19.9	11.3

the grade 2 samples except for the Rivers Inlet and Pender Harbour areas.

Effect of increased temperature and time of processing on color. Samples from 10 sockeye salmon with an average *a/b* ratio of 1.74 when raw, were processed in the usual manner at 116° C. for 20 minutes after which the average *a* value of the canned samples was 22.6. From the same fish another 10 samples with an *a/b* ratio of 1.76 were processed at 121° C. for 90 minutes, resulting in an average *a* value of 21.1 for the canned products. A third group of 10 samples from the same fish with an average *a/b* ratio of 1.79 was processed at 116° C. for 2 hours, the resulting canned samples having an average *a* value of 21.0. These data show that a 5° C. increase in the temperature of processing or a 30-minute increase in the cooking time resulted in an increased color loss.

Effect of post-mortem storage conditions on color. Samples were taken from fresh sockeye salmon for

TABLE 5

The effect of post-mortem storage in ice and refrigerated sea water on the color of canned salmon

Post-mortem storage	No. of fish	Average *a/b* ratio of raw samples	Average *a* value of canned samples
None	10	1.66	21.5
10 days in ice	10	1.74	21.4
None	4	1.67	20.8
12 days in seawater at −1.1° C.	4	1.73	21.0
6 days in ice	11	1.69	20.4
6 days in seawater at −1.1° C.	11	1.72	19.1

immediate color measurements while the remainder of the fish was stored in either crushed ice or refrigerated sea water at −1.1° C. for color measurement later. Another batch of fish was divided crosswise into 2 equal parts to permit simultaneous storage in ice and refrigerated sea water. The results, shown in Table 5, indicate that the color of canned salmon was not adversely affected by the post-mortem storage of the raw fish in either ice or refrigerated sea water.

SUMMARY

This study has shown that the Gardner Color-Difference Meter is a suitable instrument for the color measurement of raw and canned sockeye salmon. It was found that the *a* reading alone is a suitable measure of the color of canned salmon and can be best predicted from the *a/b* ratio of the raw fish. Three grades with specifications in terms of color measurements of both raw and canned fish have been proposed.

It was found that in general the canned salmon with the higher oil content had a more desirable color.

Small increases in the time and temperature of processing resulted in slightly greater color losses.

Color losses during processing were not significantly affected by the post-mortem storage of the fish in ice or refrigerated sea water prior to canning.

Acknowledgment

The authors thank Mr. I. I. Bitners for technical assistance.

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ANTIBIOTICS IN FOOD PRESERVATION

BY

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Paper given at the 23rd Annual Conference of the Canadian Institute of Sanitary Inspectors, in Vancouver

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Certain highly nutritious foods - fish, meat, milk and poultry—are, unfortunately, quite as nutritious for spoilage bacteria as they are for man himself. Consequently, man is involved in a continuing struggle to control the depredations of these organisms on his food supply.

The means of control he employs may be grouped under two general headings—physical and chemical—and are used singly or in combination. It is my purpose to describe for you some of the advances that have been made in recent years in the use of certain chemical agents of control of bacterial spoilage, and particularly their use in combination with refrigeration. These chemical agents have been termed antibiotics. This is an arbitrary, and, from a psychological standpoint, perhaps unfortunate distinction; for, while there is no real dividing line between antibiotics and other chemical agents, as a result of its medical usage the term tends to be automatically associated with hypersensitive reactions in humans, and with the development of resistance to the effects of the chemical by originally sensitive bacteria. These matters have been the subject of rather confused thought by many people. It is essential that the use of each antibiotic, or chemical, be considered individually. Thus one antibiotic may be toxic when introduced parenterally but not when taken orally, another may be non-toxic in most respects but may be one to which consumers may readily become sensitized, while still others may be useful in medicine and at the same time be valuable as food preservatives.

Before considering specific examples of uses of antibiotics in food preservation, a few general remarks applicable to all foods might be in order. Antibiotics do not sterilize foods, they only retard the growth of bacteria already present in food. Thus they are most useful when the total number of spoilage organisms is low at the start. In other words they are most effective when used under the most sanitary conditions. They will not recover partially spoiled or highly contaminated foods. It will be obvious

that in these aspects antibiotics are very similar to refrigeration in relation to food preservation. But while the use of refrigeration is applicable in a rather general way, the use of any one antibiotic is not. Thus, while streptomycin appears to have no value in the preservation of fish or meat, it can inhibit bacterial soft rot in certain fresh vegetables.

There is no doubt that suitable antibiotics and refrigeration combined can preserve perishable foods more effectively than can either alone.

Turning now to the specific uses of antibiotics in food preservation, let us first consider their use in the preservation of fresh fish. Dr. Tarr of the Vancouver Technological Station of the Fisheries Research Board of Canada not only first demonstrated the usefulness of antibiotics for preservation of fish, but also was among the first to suggest their possible usefulness for food preservation in general. In 1942, during the course of a "screening" program to ascertain the possible value of various chemical substances for preventing the decomposition of fresh fish by bacteria or other micro-organisms, he investigated the use of an antibiotic, penicillic acid. This proved to be effective. However, as other antibiotics became available, further tests were conducted. Thus sulphanilamide, sulphathiazole, penicillin and streptomycin were incorporated in ice used for icing fish or in solutions in which fillets were dipped. Of these compounds, only the sulpha drugs showed any promise, but even these were no more effective than was sodium nitrate—a compound that had been in use for some time in preservation of fish but which had certain short-comings.

Then early in 1950 Dr. Tarr commenced tests with a number of new antibiotics which were made available by different pharmaceutical firms, and as a result an observation was made which was destined to have far-reaching effects in the field of food preservation. It was found that Chlortetracycline (CTC), oxytetracycline (OTC) and Chloromycetin all were effective in retarding bacterial spoilage of fresh fish. Two years later he published in some detail the results of extended experiments in which about fifteen different antibiotics had been studied for their effectiveness in delaying bacterial spoilage of fish and meats at temperatures between 0 degrees and 20 degrees C. Briefly, the results showed that CTC was the most effective antibiotic for fresh food preservation, that it was more effective than OTC, and considerably more effective than chloromycetin. The effectiveness of CTC was outstanding, for concentrations as low as 0.5 and 1.0 ppm inhibited bacterial spoilage of ground fish flesh very strongly.

From 1952 to the present time the group directed by Dr. Tarr has continued and expanded its work on use of antibiotics in fish preservation, and other laboratories have initiated research concerning the preservation of chicken, turkey, beef, pork and other flesh foods. In view of the early finding that CTC was the most effective antibiotic for fish preservation, all the research at the Vancouver laboratory for several years was carried out with this antibiotic. The results of these investigations have been published and reviewed from time to time so only the significant finding will be mentioned. In the initial work with ices containing CTC, machines which prepared flake ice were used, since with this method of ice manufacture no problem of distribution of the antibiotic occurred. In exploratory experiments, ices containing 1, 2 and 4 ppm of CTC were made, and when used with well-iced lingcod, all three ices appeared to be about equally effective in delaying bacterial spoilage. As a result of these successful tests,

experiments were conducted to ascertain whether CTC ice could improve keeping quality of salmon. Ice was prepared to contain a calculated 1.25 ppm of CTC and microbiological assays showed an average of 1.07 ppm in ice removed from fish boxes on arrival in Vancouver. Bacteriological and organoleptic examinations indicated that, with well-iced coho and red spring salmon, the CTC ice exerted a very important improvement in keeping quality. Conservative estimates indicated at least a 5-day increase in comparison with fish stored in ordinary ice. Last summer it was suggested that tests be conducted in the "groundfish" fishery. In this fishery large vessels use otter trawls to catch different species of "soles" (flatfish), grey cod and "sea bass". These fish do not command nearly as high a price as do halibut and salmon, and are therefore usually not iced very carefully, and are not eviscerated at sea. Consequently, there is a serious bacterial spoilage problem. Block ice containing 2.5 ppm of CTC was prepared, using carboxymethylcellulose in a method to be referred to later, and this ice was crushed and used in icing experiments in comparison with ordinary crushed block ice. The level of CTC was higher than that used in previous trials in view of the usual poor icing procedures. Bacteriological examination, together with the reaction of the vessels' captains, indicated that there was a marked overall improvement in quality of the fish. In addition to these trials, tests were carried out by a Northern British Columbia firm with ice containing 2.5 ppm of CTC in the Alaska area halibut fishery. Professional halibut graders and officials who are familiar with halibut reported that the fish landed were in unusually good condition in comparison with fish normally landed from this area.

In addition to work from the Vancouver Station reported above, there are available published reports of the effectiveness of antibiotics in fish preservation from several other laboratories. A few years ago, Dr. Farber of the G. W. Hooper Foundation of the University of California, reported that immersion of fillets in 2 ppm solutions of CTC and OTC caused marked reduction in their susceptibility to bacterial spoilage, the former antibiotic being somewhat more effective than the latter. A more recent report from the same laboratory showed that a two-minute immersion in 5- or 25-ppm solutions of CTC, OTC or tetracycline (TC) caused a marked improvement in keeping quality of fillets stored at 6 degrees C., and that CTC was the most effective of 14 antibiotics investigated.

During the past two years, Dr. Shewan of the Torry Research Station in Aberdeen, Scotland, has been responsible for conducting a number of trials concerning the effectiveness of CTC ice in the British cod fisheries. In initial work he found that this ice extended the keeping quality of cod about seven days. Last year he reported that ice containing 5 ppm of CTC was much more effective than that containing certain other chemical compounds tested, and stated that with white fish such as cod and haddock stored in CTC ice, "the point of inedibility was reached some seven to ten days after it was reached in the controls". In Japan, Dr. Tomiyama and his collaborators have conducted very extensive trials with CTC in fish preservation. It is impossible to cover in any detail the results of their experiments. Briefly, they found that very marked improvements in keep-quality of round herring and sardines, and of mackerel, occurred when these fish were, in various experiments, held in refrigerated sea water

containing CTC or in ice containing 5 ppm of the antibiotic, or were dipped for an hour or two in 10-40 ppm CTC solutions.

About a year ago the Fourth Annual Symposium on Antibiotics held in Washington, D.C. featured for the first time a number of papers concerning the use of antibiotics in food preservation, and a discussion panel on the subject. One of the papers presented reviewed work which was carried out with 19 antibiotics in experimental preservation of fish at 42 degrees F. In this work CTC proved more effective than OTC and TC. In other papers in which rather high concentrations of three tetracycline antibiotics (5- to 20-ppm) were compared for their effectiveness in preventing spoilage of salmon species and of sole stored in chilled salt solutions, it was reported that all were about equally effective. Recent work in the Vancouver laboratory, which was reported last May at the Annual Meeting of the Institute of Food Technologists in Pittsburgh, has verified previous findings that CTC is consistently more effective than OTC or TC when used in fillet-dipping or fish-icing procedures, and also appears to be more effective when used with fish held in refrigerated salt solutions. In refrigerated sea water the comparatively anaerobic conditions which prevail cause a different type of spoilage from that found with iced fish, and a detailed study of this rather unusual spoilage pattern is in progress.

In general, though CTC has proven of considerable value in retarding spoilage of shellfish such as oysters, cooked crab meat and shrimp, the concentrations required for successful preservation have been considerably higher than those which have been successful with fish. So far no adequate explanation of this fact has been advanced. It is doubtful if the pH of the tissues is a factor as oyster meats usually possess slightly acid reaction, while with shrimp and crab meat the reverse is true. Preservation of menhaden for reduction has been successfully accomplished by use of a CTC spray.

The problem of preservation of whales is difficult, as the carcasses of these warm-blooded mammals undergo extensive anaerobic bacterial spoilage if they are not processed in 16-24 hours after capture. During the past two whaling seasons Dr. Tarr's group carried out trials in a local shore whaling operation in which 50 to 100 grams of pure CTC were dissolved in about 20 gallons of sea water and injected into the visceral cavities of the animals. The results of initial tests were so promising that last year 45 whales were treated. Bacteriological examinations of tissues taken from seven regions in each whale indicated a considerable overall improvement in quality, and the work is being extended this year. It is planned to conduct more extensive trials in which the antibiotic will be used in the harpoon head as well as introduced by the injection method.

Though some papers dealing with antibiotic treatment of meat in attempts to retard spoilage were published in 1950 and 1951, it was not until the group at Ohio State University under Dr. Deatherage undertook research on this subject that real progress was made. This work has appeared in a number of scientific papers during the last few years. It is interesting to note that the Ohio State investigators came to the conclusion that, of several antibiotics studied, only CTC, OTC and chloromycetin gave promising results, and that of these CTC was most effective. Initially it was shown by the Ohio State group that, of 92 separate bacterial strains

representing 12 genera isolated from meat, 81 were sensitive to CTC, 77 to OTC and 74 to chloromycetin. Observations led to the conclusion that in the deep tissues of beef animals the main centres of bacterial infection were the lymph nodes. Beef rounds were pumped with 55 parts per million of CTC in physiological saline, and when these were stored 2 days at either 3 degrees C. or 25-30 degrees C. it was found that the total bacterial populations of excised lymph nodes from treated animals represented only a small fraction of those obtained in nodes from untreated animals. These relatively small-scale investigations were followed by studies with whole animals infused **post-mortem** via one carotid artery, and the results showed that the CTC treatment retarded bacterial spoilage very significantly. Surface bacterial growth on carcasses was strongly retarded by using a CTC spray. Microbiological assay results indicated that residual CTC gradually disappeared in stored meat, the rate of disappearance being much more rapid at higher temperatures (e.g. 25 degrees C.) than at lower temperatures (e.g. 3 degrees C.). Some investigators believe there are significant possibilities in injecting antibiotics such as CTC peritoneally into live animals one or two hours prior to slaughter. The difficulties inherent in this method, such as the relative insolubility of tetracycline antibiotics and high residual concentrations in internal organs of injected animals, has been emphasized by Deatherage, who does not think that this route is very practical. However, some success has been achieved by other groups of investigators who have used relatively soluble oxytetracycline derivatives. Naturally it is easy to apply an antibiotic treatment to ground meat products.

Antibiotic treatment of poultry as a preservative measure was first explored about 1954 when the efficiency of CTC for this purpose was demonstrated by Drs. Ziegler and Stadelman of the State College of Washington .The fact that, in order of effectiveness, CTC, TC, and OTC were the useful antibiotics for this purpose was also demonstrated at about this time by Dr. Kohler **et al** of American Cyanamid. Since these original observations were made there has been further research on this subject, and the treatment of freshly killed poultry with CTC to extend the "shelf-life" received official permission in the United States in 1955. A recent report by Dr. Ayres **et al** of Iowa State College described a study of tetracycline and other antibiotics, and of combinations of CTC with antifungal antibiotics, in preservation of dressed chicken. The results showed that under most conditions CTC was more effecttive that OTC, that the antifungal antibiotics suppressed yeast growth which tended to occur in CTC-treated birds. Earlier work by Tarr **et al** had shown that the antifungal antibiotic rimocidin retarded yeast growth which tended to occur after rather prolonged storage in CTC-treated fish or meat samples.

Attempts to use antibacterial effects produced by antibiotics to reduce the processing time of canned vegetables has yielded interesting results, but as yet the general method has not reached the stage of practical application. The principle involved is that of the action of certain antibiotics such as subtilin in retarding development of germinating spores, the action being enhanced by application of mild heat. Investigations have shown that, of some 90 antibacterial substances examined, only subtilin and nicin were really effective in reducing thermal resistance of spores of certain food-poisoning bacteria. It would seem that there are still pos-

sibilities in intelligent applications of these or similar findings. Active research is proceeding in the subject of preservation of fresh fruits and vegetables with antibiotics, but the results have not as yet been promising because rather high antibiotic concentrations are required.

It is doubtful whether any preservative should be used in market milk as proper production, handling and pasteurization procedures ensure a safe product. However, in countries which are as yet backward in their food handling procedures antibiotics could be used to advantage, and the tetracyclines appear to be most effective for this purpose. Nisin-producing **streptococci** retard devolpment of **Clostridia** in cheese and the antibiotic itself has been used advantageously to control gassy fermentations in this product.

The subject of antibiotic residues in treated foods has been viewed with concern in some quarters. With poultry there appears to be no difficulty with residues of CTC since normal cooking procedures destroy it. On the other hand, the comparatively light cooking procedures which are usually advocated for fish may result in very small amounts of CTC remaining in the product after cooking. It was shown in the Vancouver laboratory two years ago that about 95% of added CTC is destroyed by heating fish flesh 5 minutes at 99 degrees C. More recently this laboratory has studied the effect of certain normal fish-cooking procedures on the amounts of CTC which remain in fish which had been iced with ices containing between 2- and 4-ppm of CTC in the laboratory, or on fishing vessels. In the uncooked fish the highest residue found was 0.6 ppm in a unskinned fillet. Residues in the cooked flesh varied with the method of cooking and with the area sampled, amounts of from 0 to 0.3 ppm being found. It was observed that, since the dark skin of fish is rarely consumed, and antibiotic residues are highest in this region, it is highly unlikely that consumers of CTC-treated fish will receive over 0.1 ppm of the antibiotic. CTC residues in whole eviscerated fish stored in refrigerated sea water, or dipped in CTC solutions are inclined to be higher than those found with iced fish, but the values are variable depending on the size and variety of fish and the concentrations of CTC used. The values reported for uncooked fish by United States investigators in general compare favourably with the results recorded above. Recently, Dr. Tomiyama has shown that fish held from about one to two days at 4 degrees C. in sea water containing 10 ppm of CTC contain from 0 to 2.8 ppm, but that the antibiotic is, after this comparatively short storage period, in the skin and gills of the fish and not in the flesh or viscera. With the experimental technique employed these investigators found that it would require 26 minutes at 93 degrees C. to inactivate 90% of CTC in fish muscle. Dr. Shewan has observed that, "Indeed, in the skinned, minced raw muscle from fish stored 28 days in ice containing 5 ppm CTC it has been difficult to detect any CTC at all." On the other hand, he found quite high concentrations (3.5-11.1 ppm) in the skin. It would appear from the results obtained in these four widely-separated laboratories that typical applications of CTC to fish for preservative purposes will usually result in small but detectable residues in the raw uncooked fish. However, these residues are concentrated mainly in the skin, or gills of the fish, and are largely or entirely inactivated by heating. With concentrations of CTC of the order mentioned above it would be necessary to consume about one ton of raw fish or ten tons of

cooked fish to ingest one normal daily therapeutic oral dose (1 gram) of the antibiotic.

The general harmlessness of CTC when administered orally is well known. Premature infants and children have been fed daily oral doses of CTC ranging from 20 to 50 mg. in some instances for 35 months, without any harmful effects. Though nausea may arise in adult patients treated with therapeutic doses of CTC, the available literature indicates that at comparatively low levels the antibiotic is tolerated well with no cumulative toxic effects, even after many months. In geriatric patients long-term administration of CTC has never been followed by lasting toxic manifestations. The extraordinary ability of rats to tolerate CTC is brought out by an experiment in which these animals were fed a ration containing 1% of the antibiotic with no adverse effects, when compared with appropriate control animals. Experimental data indicate that isochloretracycline, the bacteriostatically inert compound which arises from CTC when it is heated as in cooking of flesh foods, is non-toxic. An interesting and important point is that, though research in the United States has shown that about 5% of market milk samples contain significant amounts of penicillin, which arise as a result of use of this antibiotic in treatment of cows for mastitis, in no case has any instance of hypersensitive reacton in humans been traced to ingestion of such milk. Penicillin is one antibiotic to which humans readily develop hypersensitivity.

The only potential danger in use of antibiotics such as CTC in fish, or other flesh foods, would appear to lie in misuse. Application to fish of poor bacteriological quality is useless; only strictly fresh fish should be treated. If fishing vessels are kept clean, the danger of difficulty arising plications may result. It may be emphasized here that the presently accepted methods of using the tetracycline antibiotics in preservation of fish or poultry **are an adjunct to adequate refrigeration and not a substitute for it.**

At this time the following permissions have been granted in North America for use of tetracycline antibiotics on flesh foods. In Canada, on September 26, 1956, the Food and Drugs Act and Regulations were amendin the preservation of fish which are iced with CTC ice is remote. Each fish which is brought aboard has a fresh bacterial flora which has had no previous contact with CTC. On the other hand, fillet-dipping procedures using CTC solutions could be a source of trouble if the tanks and equipment used are not properly cleaned and disinfected, for a bacterial flora resistant to CTC would be expected to accumulate. Similar precautions would be essential if CTC were added to refrigerated sea water used for the preservation of fish. As with any other food process, unless the procedure is properly carried out under prescribed conditions, failure or comed as follows: "No person shall sell fish that has in or upon it chlortetracycline if (a) the amount thereof exceeds 5 parts per million; (b) its presence is not declared by nameon the main panel of the label." More recently the use of OTC has been permitted under similar conditions. In both the United States and Canada the inclusion of not more than 7 ppm of CTC or OTC is permitted in uncooked poultry. As much of Canada's fish is presently exported to the United States, the application of antibiotic treatment of fish is presently limited to products which are consumed domestically. Shellfish such as oysters have not been included in the above

regulations because they may be consumed uncooked and properly treated oysters will contain significant antibiotic residues. At this stage consideration might be given to the desirability of permitting inclusion of small residues of tetracycline antibiotics in foods intended for human consumption. Available information does not indicate that there could be cumulative or other toxic reactions as a result of such inclusion, and development of hypersensitive reactions to small oral doses of tetracycline antibiotics does not appear to occur.

Certain difficulties have been experienced in work on fish preservation by use of CTC. The problem of obtaining uniform distribution of tetracycline antibiotics in block ice arose several years ago and this was solved by addition of colloidal gelling agents carboxymethylcellulose and carrageen. Low concentrations of these agents of the order of 0.01% are adequate for occasioning comparatively even distribution of tetracycline antibiotics. Another problem which has arisen, and which has not yet been solved satisfactorily is that of the presence of substances in muscles of certain fish which occasion slightly positive CTC microbiological assays in the absence of added antibiotic. These substances seem to be present in most of the fish with which the Vancouver group has worked, and it is for this reason that in work on antibiotic residues in fish they have normally used grey cod, the flesh of which rarely gives fictitious assays. The interfering substances appear to be soluble in certain organic solvents and may be lipoidal in nature. Flesh extracts obtained by extracting with acid-acetone or with water at pH 4.5-4.6 are both capable of containing these interfering materials. Since these materials may cause false assays which are equivalent to about 0.25 ppm of CTC, it can be appreciated that it may be impossible to distinguish readily traces of the antibiotic in flesh of some treated species of fish unless tedious extraction and chromatographic techniques are applied.

In the course of this review several promising uses of antibiotics in food preservation have been mentioned, but as has been pointed out only two have been approved for use in Canada. It appears very probable that other applications of antibiotics as food preservatives at present in the experimental stage will eventually be found to be valuable and be accepted, but much more research and development work is needed. Fundamental knowledge regarding the nature of action of antibiotics and the mechanism of the development of resistant strains of bacteria is desirable.

Finally, although in the foregoing the use of antibiotics in conjunction with refrigeration has been emphasized, it should be pointed out that antibiotics have one important advantage over refrigeration in food preservation. The capital equipment costs are relatively low for processing with antibiotics. Hence, in areas where refrigeration is not available, antibiotics may eventually present a less expensive means of increasing keeping time, thus enabling more efficient and less wasteful distribution of food.

Reprint from The Canadian Fish Culturist, No. 21, December, 1957, published by the Department of Fisheries of Canada, Ottawa.

The Importance of Size in the Change from Parr to Smolt in Atlantic Salmon

by

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The factors associated with the metamorphosis of young Atlantic salmon from river-dwelling parr to seaward-migrating smolts have not been very well defined. Size has been regarded as an important factor by some investigators and relegated to a minor position by others. Pyefinch (1955) gives a useful review of literature on the subject of this change from parr to smolt. Svardson (1955) suggested a set of hypotheses involving "physiological age" of the individual fish in combination with environmental considerations. Most investigators have concentrated their attention on the young salmon near or during the immediate season of migration. Vibert (1950), however, offered evidence that age at migration had been set by the end of the first winter of river life.

Salmon production of the Miramichi River system, in New Brunswick, has been investigated by the Fisheries Research Board of Canada for the past seven years. Part of the program calls for knowledge of the numbers of smolts produced. Direct counts have not been attempted in the larger tributaries because log drives prevent weir operations during part of the run. Indirect estimates are consequently necessary. These rely upon a combination of seining and electrofishing done late in the summer. In the Miramichi system approximately one-third of the smolts migrate as two-year-olds and two-thirds as three-year-olds. Observations by Canadian investigators indicate that size, or physiological condition associated with size, of parr in their pre-smolt year seems to be a more important factor than age in the change from parr to smolt. As a working approximation an arbitrary dividing line between large parr, likely to become smolts next spring and small parr, not likely to, has been set at about 10 cm. or 4 in. total length, measured from tip of snout to tip of tail. From the facts assembled here it appears that there is justification for using this convenient rule of thumb.

Evidence from hatchery yearlings

In mid-June, 1945, hatchery-reared yearling Atlantic salmon of sea-run, and of lake, or landlocked, stocks were being planted in the Rawdon River, Grand (Schubenacadie) Lake system of Nova Scotia. It was observed that the larger fish of both stocks had a heavy, silvery coating of guanin on their scales, much more than is normal for river-dwelling parr of comparable size. Other smolt characteristics such as low condition factor and easily loosened scales were apparent to a minor degree. Enquiry to the Department of Fisheries revealed that all the fish "had been fed (chopped) plucks and fish through January to the time of examination (June 16), except that they

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were fed fish only during the second and fifth weeks of May. It is quite possible that the thyroid gland was included in the plucks which were fed.....". Hoar (1939) has shown that the change from parr to smolt stage, which he terms a true metamorphosis, is associated with greatly increased activity of the thyroid gland. Robertson (1949) showed that in large (9 to 10 inches) two-year-old rainbow trout (*Salmo gairdneri*) the silvery smolt stage could be induced by intra-muscular injection of mammalian thyroid extract. Hoar (personal communication) has expressed his opinion that "certainly fresh thyroid gland in the food supply should tend to initiate a smolt transformation".

At the time of the observations above, approximately 300 fish from each stock were taken at random from the supplies in the hatchery's holding ponds. Each fish was classified according to the extent of its silvery colour as "parr", or "smolt". The fish were measured and mean lengths were calculated for each of the categories in both stocks. For both kinds of salmon there was a fairly clear-cut division into large, silvery "smolts" and into smaller "parr" without obvious silvery colour. These size groupings are shown in Figure 1. There was some overlapping of sizes between parr and smolts but there was no silvery coloration on fish of sea-run stock under about 11½ cm. or on lake stock under about 10½ cm. long.

Comparison between sea-run and lake salmon is shown in Table I.

Table I.

Lengths (cm.) of yearling salmon of sea-run stock and of lake stock, from the Schubenacadie Grand Lake Rearing Ponds, Nova Scotia. (Measured June 16, 1945.)

	Parr			Smolts		
	Number Specimens	Mean Length	Standard Deviation	Number Specimens	Mean Length	Standard Deviation
Sea-run.....	264	10.2	±1.0	65	14.2	±1.3
Lake.....	238	9.7	±1.4	52	13.8	±1.5

The difference in size of the two stocks seems largely attributable to the lake salmon growing more slowly than the Atlantic salmon. In keeping with this a slightly smaller proportion of lake salmon (18%) than of sea-run salmon (20%) showed the change from parr to smolt. Wilder (1947) also found relatively slow growth to be a characteristic of lake salmon.

The data show that both the sea-run and lake salmon stocks conformed to a general size characteristic in relation to the incidence of guanin deposition. The evidence does not show that the fish became smolts at a specific size of about 10 cm. Rather it shows that, for both stocks, only those fish which had already reached 10 cm. were subject to the change from parr to smolt.

This evidence of a size prerequisite for transformation of hatchery-reared fish should be useful to fish culturists in planning salmon-rearing programs for particular purposes. For example, in a stream where smolts are typically three years old, fingerlings planted in one summer would be expected to produce a smolt run three years

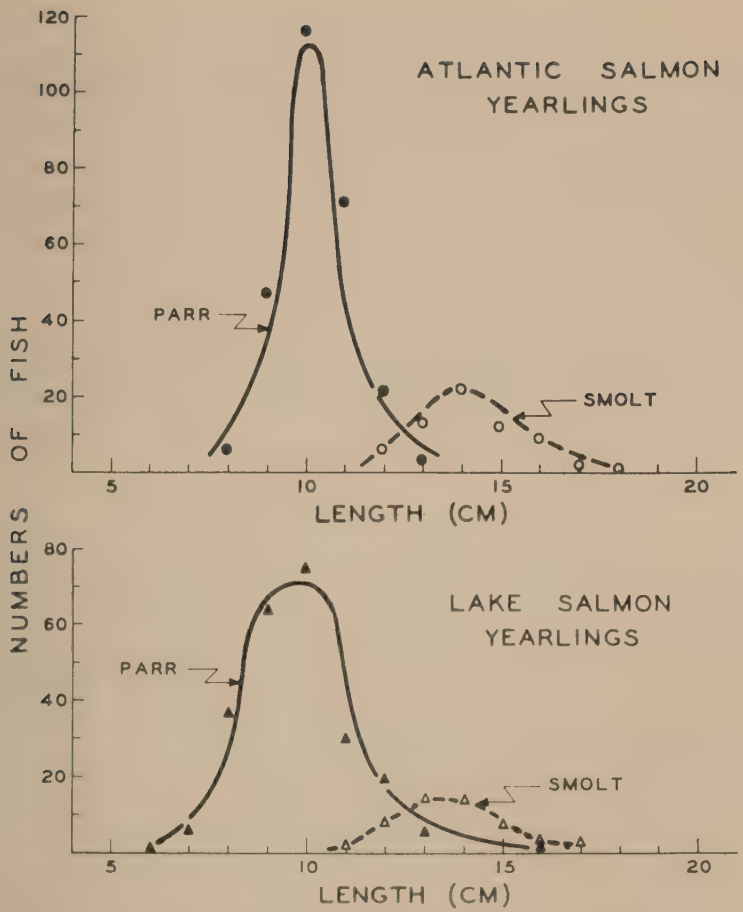

Figure 1.—Length-frequency distribution of hatchery-reared yearling salmon of Atlantic and lake stocks, classified as parr having no obvious silvery guanin deposit on the scales, and smolts having a heavy guanin deposit. Only fish over 11½ cm. (Atlantic) and over 10½ cm. (lake) showed this smolt characteristic. (Fish examined at Grand Lake Rearing Ponds, N.S., June 16, 1945)

later; planting small parr should yield a run only two years after planting, and planting large parr one year after. Liberating smolts directly from the hatchery is proving worth while for one Swedish river from which salmon have been excluded by a dam (Carlin, 1955). Programmes using hatchery-reared smolts might benefit by consideration of such a size prerequisite. This subject is now being examined through experimental plantings.

Evidence from Pollett River Smolts

During the course of experiments involving Atlantic salmon smolt production from the Pollett River, Petitcodiac River system, New Brunswick, scales from several thousand smolts were examined. For the most part age determinations only were made. Here, 90 to 95 per cent of the smolts run as two-year-olds, and almost all the

rest as three-year-olds. Measurements of scale radii for the several years of river life were made on 250 typical samples from the 1950 smolt run. For the 14 three-year-old smolts measured, the calculated mean length and standard deviation at the end of the second winter was 10.7 ± 0.8 cm. For a representative group of 22 two-year-old smolts from the same migration, calculated mean length at the end of the second winter was 14.0 ± 1.7 cm. Examination of scales from Pollett parr collected monthly through most of a year indicated that usually about one-quarter of the growth for the year occurred during the laying down of the winter band, between about Mid-August and the following May. In consequence most fish which were about 11 cm. long by the time the winter band was completed were probably well under 10 cm. long in the preceding August: but those which were around 14 cm. long, or longer, in May must have been at least 11 or 12 cm. long in the preceding August. These Pollett young salmon conformed fairly well to the hypothesis that those which exceed a length of 10 cm. by late summer, become smolts in the following spring; while those which do not attain this size remain in the river for an additional year or more.

Evidence from Scotland—Thurso River

Allen (1944) made an extensive study of salmon smolts from the Thurso River system of northeastern Scotland. In his Table VII he gives the lengths at smolt stage and calculated lengths at the end of the immediately preceding winter for 1,317 two-year-smolts. These are expressed as mean lengths for fish captured during successive five-day periods. The general mean for all fish at the end of the preceding winter was 10.6 cm. Only two groups totalling 50 fish, or 4 per cent of the collection, had a mean length under 10 cm.; and it was 9.5 cm. at the end of the preceding winter. Unfortunately Allen does not give first- and second-winter lengths for the small percentage of three-year smolts he recorded. However, the fact that 96 per cent of his two-year smolts reached the 10 cm. length at this time, and the rest nearly attained it, gives support to the hypothesis that there was a size prerequisite for the change, which was of the same general order as that observed in Canada. Allen concluded that "there is no critical length at which migration takes place". But he concurred with earlier authors, that "parr must attain some physiological condition associated, at least as an index, with a minimum size before the smolt migration takes place". The hypothesis that this condition is associated with a length requirement of about 10 cm. during the latter part of the pre-smolt year of growth, is not at variance with the conclusions drawn by Allen.

Evidence from England—The Cheshire Dee

Jones (1949-Appendix, Table II) gives the calculated yearly lengths of 335 smolts taken from the River Dee, Cheshire, in 1938 and 1939. He had one-, two- and three-year smolts. Nearly 92 per cent of these fish satisfy the present hypothesis. Dee smolts which did not conform were those migrating at 1+ years. But even these had all made rapid growth during the first season—$7\frac{1}{2}$ to $9\frac{1}{2}$ cm. against $4\frac{1}{2}$ to 5 cm. Rapid spring growth in the season of descent brought them to about $12\frac{1}{2}$ cm. Since a large majority of the fish conform, the 10-cm. hypothesis should be useful in studying late summer parr populations in such a stream.

Evidence from France—River Adour

Vibert (1950) gives calculated mean lengths at the end of each year of river-life for 492 smolts and 1,022 virgin salmon, in his Table XIV. Nearly all the fish conformed in that they did not migrate if they had not reached the 10-cm. length, but migrated in the next spring, after reaching or exceeding an approximate 10-cm. length towards the end of a growing season. One three-year smolt reached a length of 11 cm. at the end of its second year, as did one of Jones' three-year smolts from the River Dee. Since the 10-cm. hypothesis is based on mean lengths in late summer rather than the length of individual fish at the end of a year's growth these do not constitute exceptions. Among Vibert's virgin salmon, a group of 11 which had been three-year smolts had a calculated mean length of 13.6 cm. at the end of their second year of river life but still spent one additional year in the river. The fact that 99 per cent of his fish conformed to the 10-cm. hypothesis indicates that it would be a useful working rule here also.

Discussion and Summary

Evidence is presented from both sides of the Atlantic to show that, as a general rule, parr which have reached or exceeded a certain size towards the end of one growing season are likely to become smolts at the next season of smolt descent. A similar size prerequisite also appears to hold for a slower-growing Canadian lake salmon stock. In fact, the concept of a size prerequisite appears to have more fundamental significance with respect to change from parr to smolt than either age or size at the actual time of transformation.

The hypothesis definitely does not specify that young Atlantic salmon become smolts as soon as they reach a length of 10 cm., but rather that they transform after reaching this length in the smolt-running season immediately following. Growth of parr is variable. Those which have nearly but not quite reached the 10-cm. length at the end of a summer will, if they grow fast, reach a much greater length, say 14 to 16 cm., at the end of the following summer, and make big smolts. Those which have just barely attained the required 10 cm. size at the right time will, if slow-growing, make little smolts, perhaps only about 12 cm. long. The 10-cm. hypothesis thus takes account of the extremely variable size-range of smolts from many types of rivers.

Some individuals destined to become older smolts may exceed this length, but seldom by more than two or three cm., at the end of their second last season of river growth. A few fish may not quite reach this size but still become smolts during the following spring if they grow fast and exceed the 10-cm. length during the smolt-running season. While not precise for individual fish, this 10-cm. hypothesis provides a useful and justifiable rule of thumb for gauging annual smolt production from streams.

Canadian investigators of Atlantic salmon at present classify young salmon as "small" parr, those which will probably spend one or more additional years in river growth, and "large" or "pre-smolt" parr, those which are likely to descend as smolts during the next seaward migration. The arbitrary division between the two groups of parr has been chosen at a total length of 10 cm. or 4 in. reached during the latter part of a year's growth.

Use of the hypothesis should contribute to effective planning of salmon-rearing programs for hatcheries, if special purposes can be served by planting larger fish.

Acknowledgments

The Grand Lake salmon were examined while assisting Dr. A. G. Huntsman in his investigations there; he kindly made time available for the observations on hatchery stocks. Mr. William Cameron, Superintendent of the Grand Lake Rearing Ponds, assisted in handling these yearling salmon. Mr. W. G. Carson of this Station made the scale measurements for Pollett smolts while reading some 2,000 smolt scale samples from this stream. I thank these gentlemen for their help.

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EDMOND CLOUTIER, C.M.G., O.A., D.S.P.
QUEEN'S PRINTER AND CONTROLLER OF STATIONERY
OTTAWA, 1958

Reprint from The Canadian Fish Culturist, No. 21, December, 1957, published by the Department of Fisheries of Canada, Ottawa.

Using Hatchery-Reared Atlantic Salmon to Best Advantage

by

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Good management of Atlantic salmon requires knowledge of how to get the best production of seaward-migrating smolts. This applies whether the stocking be through natural means or through the introduction of hatchery-reared stock. The Fisheries Research Board of Canada has, for a number of years, been investigating factors associated with the production of smolts from hatchery-reared stock. This is a preliminary survey of the results which can be found in condensed form at the end of the paper.

Much of the following discussion will refer to numbers which can be produced, must be planted and so on. To use total numbers from experiments would have no significance for other areas than the one in which studies were made. Hence, important figures have been converted to easily imagined units. For general use the average number per 100 square yards has been selected—an area 30 feet by 30 feet, or about the size of an average house. Sometimes it is more convenient to think in terms of the length and width of a stream. For this a unit of one mile of stream 10 yards wide (176 of the square units) has been selected. The 100 square yard unit will be meant unless otherwise stated.

1. PREDATION BY MERGANSERS SHOULD BE LIMITED

Several years ago White (1939) found that a stream stocked with native salmon gave more smolts when mergansers (*Mergus merganser americanus*) and kingfishers (*Megaceryle alcyon alcyon*) were kept away. A study has recently been completed on the effect of similar bird control in increasing the smolt yield from hatchery-reared fish. Experiments were done on a 10-mile stretch of the Pollett River, a tributary of the Peditcodiac system in southeastern New Brunswick. Table I shows the total number of two- and three-year-old smolts produced from seven different plantings of underyearling salmon. Two of the plantings were quite light; five were fairly heavy. However, as will be shown in Section 2, below, even the light plantings should have experienced a better survival rate than they did. If judged solely on a comparison of the results from the heavy plantings, there was an increase of about four times with birds kept away. If judged on the average "before and after" figures, by nearly seven times.

Table I also shows the estimated number of parr in the river, midway between planting and smolt descent. It is on these parr that the birds do most of their feeding.

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Table I

Smolt production from known plantings of hatchery-reared underyearling salmon in the 10-mile experimental area (approximately 435,000 sq. yd.) of the Pollett River, N.B.

	Year of planting	Number of underyearlings planted (nearest 5,000)	Resulting parr 1 year after planting (nearest 5,000)	Resulting 2- and 3-year smolts (nearest 1,000)
With no bird control	1942	15,000	under 5,000	2,000
	1943	15,000	under 5,000	1,000
	1945	250,000	10,000	5,000
Average		over 15,000	5,000	3,000
With control of mergansers and kingfishers	1947	275,000	25,000	22,000
	1948	235,000	45,000	14,000
	1949	245,000	40,000	19,000
	1950	245,000	55,000	24,000
Average		250,000	40,000	20,000

Records were kept of all birds seen. The food recently eaten by many of those shot was studied. In Table II estimates are given of the number of fish which the birds could have eaten had there been no control. There are also estimates of the numbers that could have been eaten by those birds which escaped the patrols. Without control, enough mergansers visited the area to eat more parr than the river could support. But with control the remaining mergansers could take only about one quarter of the parr when there was a good parr crop. This is not enough to seriously affect the smolt-producing capabilities of the stream.

Table II

Estimated numbers of fish which visiting mergansers and kingfishers could eat annually while on the 10-mile experimental area of the Pollett River.

	Mergansers		Kingfishers	
	All fish	Young salmon	All fish	Young salmon
Without Control	180,000	75,000	120,000	10,000
With control	20,000	10,000	10,000	1,000

Year-to-year records showed that when parr were more abundant, more mergansers came to the area. They came any time of the year that there was open water on the river (Fig. 1).

In general, the rate of production when mergansers had free reign was about one smolt per 100 square yards of stream. With bird control, production jumped to a rate of five to six smolts per 100 square yards.

Figure 1.—Mergansers on a New Brunswick salmon stream in mid-winter.

Surveys have shown that mergansers are as abundant on many Maritime streams as they were on the Pollett. But they are furtive birds and their abundance can easily be underestimated. To get the best results from hatchery-reared stock, or native stock too, for that matter, mergansers should not be more abundant than about one bird for every 10 to 15 miles length and 10 yards width of stream.

Kingfishers, as shown in Table II, could not remove enough young salmon to seriously affect the smolt output unless the birds were to increase greatly in numbers. Their habits make them conspicuous along a stream. Because of this, in contrast to mergansers, it is very easy to overestimate their abundance and their importance to salmon. It is doubtful that the results of controlling kingfishers along most salmon streams would warrant the trouble and expense. However, if they were more abundant than two for every mile length and 10 yards width of stream, control might be worth while.

2. HOW MANY FISH SHOULD BE PLANTED?

To know how many fish to plant it is first necessary to know how many smolts an area can produce.

Smolt producing capacity of streams. The bird control studies mentioned above showed that the 10-mile stretch of the Pollett could produce smolts at a rate of about one per 100 square yards without bird control; but five with control. This was from

planting fingerlings at rates of 55 to 60 per 100 square yards. To find out whether planting more fingerlings would give more smolts a planting was made at the rate of 213 fingerlings per unit area—about four times as many. Data are given in the two top rows of Table III. Smolts were produced at the rate of six per unit area. This is not sufficiently different from five smolts to be regarded as anything more than the difference between years with favourable or unfavourable conditions for survival. That is to say, the maximum capacity with bird control can be set at five to six smolts per 100 square yards.

Table III

Smolt production and survival rates from heavy, medium and light plantings of underyearlings and one small accidental spawning in a 10-mile stretch of the Pollett River, N.B. Total experimental area = 435,000 sq. yd. (a) Accidental spawning resulted when exceptionally high freshet brought a few adult salmon past a closed fishway into the experimental area. (b) "Best survival rate" from planting to parr was approximately 25%. (c) "Best survival rate" from parr to smolts averaged approximately 65%.

Number of underyearlings planted		One-year parr per 100 sq. yd.	Survival rate underyearlings to parr %	Two-year smolts		Survival rate parr to smolts %
total	per 100 sq. yd.			per 100 sq. yd.	total no.	
925,000	213	16	8	6	23,750	34
240,000	55	15	27(b)	5	22,852	35
65,000	15	4	27(b)	2	8,052	51(c)
accidental(a)	—	over 1	—	under 1	3,556	80(c)

Observations on young salmon in Miramichi streams (Elson, 1957a) indicate that the smolt producing capacity of these streams, both without and with bird control, is similar to that found for the Pollett. A relatively infertile stream in the Gaspé peninsula of Quebec, the Port Daniel River, also gives smolts at the approximate rate of one per 100 square yards; not enough mergansers visit this stream to warrant their control.

Survival rates from fingerlings to smolts. The plantings which gave maximum smolt production may have wasted quite a few fry. In fact, compared with results of the planting made at a rate of 55 fry, planting 213 fry did waste about three quarters of the fish. To discover the "best survival rate" when no such wastage was involved, a planting was made at about one quarter of the first rate (actually, 15 fry per 100 square yards). This and other measurements of "best survival rate" from sparse populations, which means no unnecessary wastage, are given in the last two lines of Table III. The best survival rates from fry to yearlings were a bit over 25 per cent. The best survival rates from sparse parr populations to smolts averaged 65 per cent. This gives over 16 per cent as the survival rate from fry to smolts. To play safe the general rate from late summer fingerlings to two-year smolts should be 15 per cent.

Although the smolt capacity of Miramichi streams is apparenly about the same as the Pollett, there is one important difference. Where nine out of 10 Pollett smolts are two years old, seven out of 10 Miramichi smolts are three-year-olds. This means Miramichi parr must go through an extra year in the river, during which there is some

mortality. Here again the observations in the Miramichi area indicate that the survival rate over this extra year is of the same general order as the rate over the last year on the Pollett, i.e., about 65 per cent. So the survival rate for three-year smolts from late summer plantings of fry should be set at only 10 per cent.

It would be useful to know from which streams to expect three-year smolts and which streams two-year-olds. Smolt age appears to be clearly associated with water temperature. In general, warm streams, say over about 68°F. (20°C.) in summer give two-year smolts. Cool streams, say 60°F. to 65°F. give three-year smolts. In still colder, or in very infertile streams, smolt age may be increased to four, five or even eight years; but smolts this old are uncommon in the Maritimes.

Number to plant. The best number to plant is that which will give the full capacity of smolts, while giving the highest survival rate from the planted fish. Approximate figures for the largest numbers of fingerlings it would be worth while to plant are:

In fertile streams with mergansers less than one per 10 miles × 10 yd. of stream.

for two-year smolts	7,000 fingerlings per mile × 10 yd. wide
for three-year smolts	10,000 fingerlings per mile × 10 yd. wide

In barren streams, or fertile streams with mergansers more abundant.

for two-year smolts	2,500 fingerlings per mile × 10 yd. wide
for three-year smolts	3,500 fingerlings per mile × 10 yd. wide

These are the highest figures. In most years planting 1,000 or so less should give nearly all the smolts the stream could raise. But planting many more is almost certain to result in waste of all the excess either through predation or starvation.

3. AMOUNT OF DISPERSAL AT PLANTING.

There are two aspects to this: the amount of scattering at chosen planting sites; and the distance between planting sites.

Dispersal at planting sites. The best amount of dispersal at planting received study on a section of the Pollett 10 miles above the area used for the studies of smolt production already mentioned. Three different degrees of dispersal were tested at each of three similar planting sites located two miles apart. The fish planted in each area were distinctively marked by removal of certain fins. Three years was required to complete the planting schedule. The results were measured by counting the smolts from each planting as they passed through the smolt trap 15 miles downriver (Table IV).

The final results indicate that the different degrees of dispersal had no appreciable effect on the number of smolts produced. The difference in the various smolt runs (Table IV) proves on analysis to be largely the result of good and bad years. Further, the bad years were years when mergansers were relatively abundant. No bird control, other than removal of merganser broods, was employed for these dispersal experiments. The important conclusion from this study is that nothing would appear to be gained

Table IV

Smolts produced from plantings of 4,000 underyearling salmon given different amounts of dispersal at liberation.

Dispersal at planting, as nos. per 100 sq. yd.	Number of smolts produced			
	from 1948 plantings	from 1949 plantings	from 1950 plantings	from all 3 plantings
50	1,183	1,911	618	3,712
500	1,329	1,407	868	3,604
5,000	767	1 793	972	3,532
Total smolts from plantings of 1 year	3,279	5,111	2,458	10,848

by scattering underyearlings, at planting, more widely than at a rate of 5,000 per 100 square yards at each planting site. A similar study of dispersal rates for yearlings is just being started.

Distance between planting sites. The natural spreading of the young fish away from their points of liberation was followed in several of the planting experiments mentioned above. The general picture was that the surviving fish spread fairly uniformly over the stream for about one-half mile up- and one mile downstream in one to two months' time. A year after planting they were fairly well scattered over one mile up- and downstream. A few fish travelled several miles farther than this. But the intervening stream was clearly not being fully utilized. Such lack of utilization did apply to an area two miles below the lowest liberation site through all the years of extensive planting for bird control and smolt capacity studies.

It is therefore concluded that to get full utilization of a stream's resources planting sites should, ideally, not be over two miles apart. However, access for hatchery trucks will often make this impractical; in that event some, if not full use will be made of intervening areas, even if they be several miles long.

4. SIZE OF FISH TO PLANT.

Until recently most hatchery plantings of Atlantic salmon in Canada have liberated fingerlings around $1\frac{1}{2}$–2 inches long. By holding the fish a year they can be grown to 3–6 inches long. Rearing large fish is more costly than rearing underyearlings. When is the extra expense warranted?

A common reason for planting larger fish is the hope that they may be able to escape enemies better than small fish. Consider, however, streams where mergansers are the chief enemy. Mergansers usually take parr from about three inches upwards, but seldom take two-inch fish if larger are available. In such streams newly-planted parr may not be competent in avoiding their new enemies. But their brothers planted as much smaller fingerlings are well adjusted to life in streams by the time they reach this size. Newly-planted fish face not only predators, but also competition with native fish of their own kind. As shown by Miller (1953) for a related species (*Salmo*

clarki) of the west coast this and the strain of adjustment to a new habitat may reduce survival to as low as 0 per cent–3 per cent, even for fish larger than any salmon parr.

The results of some small-scale experiments on yearlings planted in two streams of the Petitcodiac River system in New Brunswick are informative. Holmes Brook and Bennett Brook are each about five miles long and are from two to five yards wide. Both have small populations of native salmon (about two per 100 sq. yd.). In the Holmes Brook more than half the native salmon migrated as three-year smolts, the rest as two-year-olds. Practically all Bennett smolts were two-year-olds. Other fish present in both streams were eels, horned dace (*Semotilus atromaculatus*), Lake Northern chub (*Couesius plumbeus*), black-nosed dace (*Rhinichthys atratulus*) and brook trout (*Salvelinus fontinalis*) which are fished by local anglers. Occasional kingfishers visited the streams, but mergansers seldom if ever. Thus, the two brooks offered conditions similar to those on many Maritime salmon streams when mergansers are not abundant.

The hatchery yearlings, averaging about 10 cm. (4 in.) long, measured from tip of snout to end of tail, were divided into a number of small groups, some of which were of ordinary sea-run stock and some lake stock. Each lot was distinctively fin-clipped before planting. No differences in behaviour or survival value of the two stocks was noted. But considering the differently-marked groups as comprising different experiments adds to the value of the final result. All those surviving to smolt stage migrated the year after planting, as two-year-olds. This applied in both brooks. The results are given in Table V. They may be summed up, in the

Table V

Smolt production and survival rates from July plantings of hatchery-reared one-year-old Atlantic salmon parr in tributaries of the Petitcodiac River, N.B. (In 1945 both Atlantic and Lake salmon were planted in about equal numbers: in 1946 only Atlantic salmon.)

Date and place of planting.

Year	Brook	Miles above smolt trap	Number planted	Number of smolts	Survival rate %
1945	Holmes	1	26 (Atlantic)	12	23
		2½	26 "		
		1	26 (Lake)	13	25
		2½	26 "		
1945	Bennett	¼	24 (Atlantic)	1	4
		3	26 "	5	19
		5	26 "	4	15
		¼	31 (Lake)	4	13
		3	25 "	1	4
		5	26 "	3	12
1946	Bennett	¼	50 (Atlantic)	15	30
		2	150 "	22	15
		3	117 "	8	7
		4½	53 "	1	2
		5	50 "	1	2
	Total		682 1-year parr	90 2-year smolts	

Mean survival rate and its standard error ..... 13 ± 3%

statement that it is unlikely that similar plantings of yearling parr would experience an average survival rate of less than 5 per cent or more than 20 per cent.

This is not materially better than the 15 per cent survival rate which can be obtained from underyearlings (see Section 2). But the yearlings yielded smolts one and two years earlier than underyearlings would have. On the basis of these data we must conclude that if the object of planting young salmon is merely *to obtain the greatest number of smolts*, then *proper numbers of underyearlings should be planted.* Whether a similar result would apply if such predacious fish as white perch, yellow perch, and fallfish (*Semotilus corporalis*) were abundant, as they are in some salmon streams, has not been investigated. Another conclusion is that *if the object is to obtain smolts as soon as possible, then larger parr should be planted.*

By properly selecting the fish it should be possible, in a three-year smolt stream to reinforce smolt runs occurring any time between planting and three-years later as desired. In order to become smolts, parr must, as a rule, reach a length of about 10 cm. (4 in.) some months before the spring period of smolt migration (Elson, 1957b). Thus, as happened in Holmes Brook, yearling fish which will reach this length in the year of planting will make two-year smolts the next spring, even though the normal smolt age for the stream is three years. Fish which will reach only eight or nine cm. in the year of planting should make smolts two seasons later.

Hatcheries rear some young salmon to smolt stage as yearlings. Will they migrate to sea immediately, if liberated? Hoar (1939) found that the change to smolt stage was associated with increased activity of the thyroid gland. But he also found that if smolts were forced to remain in fresh water after the normal migration period this gland tended to revert to the parr condition. The migratory urge may be lost. This is indicated by the behaviour of some of the yearling fish planted in Bennett Brook in July, 1946. Among the 420 fish liberated, 16 per cent appeared to be smolts, similar to the condition Elson (1957b) reported for other hatchery yearlings. None of these Bennett fish was taken in the smolt counting weir below, in the year of planting. Several were recognized living near their original planting sites, during the summer. Occasional post-smolts which failed to get to sea have been observed in other places. They appeared to be slowly reverting to characteristic parr appearance and behaviour. Hence it would appear advisable to liberate hatchery-reared smolts early in the spring —say in May—if advantage is to be taken of their migratory urge.

Occasions may occur when the expense of planting larger fish than normal underyearlings would be warranted. The recent decimation of Miramichi young salmon by spraying of DDT has been reported by Kerswill and Elson (1955). Plantings of assorted sizes of young salmon could properly reinforce the various year-classes. But these authors found that more large fish survived the spraying than small. It may be necessary that planted fish be subjected to spraying in order to preserve the forests. If so, it would seem advisable to plant them at the largest size reasonably possible. Spraying gives rise to one situation where *only* large fish could remedy some of the deficiencies.

5. TYPES OF BOTTOM FOR PLANTING.

In the experimental plantings described, most fingerlings were liberated in water less than one foot deep, usually in rapids. Studies of the distribution of native young salmon have shown that this is the kind of habitat they prefer. It would be incurring unnecessary risk to liberate such small fish, not yet adapted to the rigours of life in streams, in pools where larger trout or other fish could readily gobble them up. Equally hazardous are areas with large cobble and rocks where eels are abundant. In the Pollett plantings, eels from about a foot upwards in length, were found to take many fingerlings within a few hours of planting in such areas.

6. EELS AS A LIMITING FACTOR FOR SURVIVAL OF UNDERYEARLINGS.

Various observations made during earlier studies, as well as the Pollett experiments, have led to the belief that eels may sometimes limit survival between fry and parr stages. The dispersal experiments described in Section 2 were carried out above the 15-foot drop of Gordon Falls. The falls is a partial barrier to eels, there being one-third as many of the sizes that eat salmon above as compared to below. Up here over 45 per cent survival to smolt stage was reached in one case, the average for the nine plantings being 30 per cent (Table III). On the lower, main experimental area, with an abundant eel population, the comparable survival rate to smolt stage was only 15 per cent. Note that this concerns survival rates from sparse populations. The bird control experiment showed that mergansers act as a limiting factor *after* eels have done their damage. Hence control of the birds is of first importance.

Studies of eels in several New Brunswick streams indicate that they are abundant in streams flowing into the Bay of Fundy, e.g. the Pollett and several tributaries of the St John (Godfrey, 1956) but that in Gulf of St. Lawrence drainages, as represented by the Miramichi River, also Ellerslie Brook in P.E.I., eel populations in the salmon-growing reaches are relatively unimportant. Higher yields of salmon, because of better survival rates, might be expected from both hatchery and native stocks where eels are scarcer, providing predation on older parr and smolts, as by mergansers, is not the limiting factor. So far no practical way of controlling eels has been devised.

7. VALUE OF ADULTS DERIVED FROM HATCHERY STOCK.

Returns to the Pollett River of mature salmon derived from stocks collected in other rivers but planted as underyearlings in the Pollett have been almost negligible. These planted fish have contributed to distant commercial fisheries; but were not identified in any river where close inspection of the stock was maintained. At present a test is under way involving the returns from 800 marked smolts of Pollett stock, reared to the usual underyearling stage in a hatchery, then planted back in the Pollett.

Summary

This summary is given in the form of brief, if somewhat categorical statements, for convenient use of the practising salmon-culturist. The statements should certainly not be regarded as the "final word" on subjects which are still under investigation. But they do have more background of observed facts than has been generally available.

(1) *Control of mergansers.* Best production of smolts from plantings of hatchery-reared Atlantic salmon, or from native salmon should only be expected if mergansers do not exceed an abundance of one bird for every 10 to 15 miles and 10 yards width of stream. Control of kingfishers is of minor importance compared to control of mergansers; kingfishers may be tolerated up to, but not above, an abundance of two per mile × 10 yards width of stream.

(2) *Numbers to plant.* For streams on which mergansers will not greatly exceed the figure of one per 10 miles × 10 yards width, and which flow through geologically fertile areas the maximum number of smolts likely to be produced is around 1,000 per mile of stream 10 yards wide. To get this number of smolts about 7,000 underyearlings should be planted, per similar area, in streams with mostly two-year smolts and about 10,000 in streams with mostly three-year smolts.

For streams with no bird control or those in geologically infertile areas, e.g. flowing largely through granite country, these figures should be reduced to about 2,500 and 3,500 fish for a maximum expectancy of 400 smolts.

(3) *Amount of dispersal at planting.* When liberating underyearling salmon at planting sites, nothing is gained by scattering them more widely than at a rate of 5,000 fish in an area of 100 square yards. Given this start, as many will survive as if they had been dispersed more widely.

Planted underyearlings will move, in good numbers, about one mile up- and downstream from planting stations. So stations should ideally be about two miles apart. But some fish will disperse to as much as several miles away, so that partial use of intervening water will be made even if stations must be farther apart.

(4) *Size of fish to plant.* Where the object is simply to obtain smolts, underyearlings will give as good results as larger parr.

But by using appropriate sizes of parr, smolt runs can be produced earlier than with underyearlings. For example, in a typically three-year smolt stream:

(a) underyearlings will yield smolts three years after planting:

(b) parr which will reach a length of eight or nine cm. in the year of planting should produce smolts two years after:

(c) parr which will exceed a length of 10 cm. in the year of planting should produce smolts one year after:

(d) smolts planted from early spring until late in May might well migrate to sea shortly after being liberated but smolts planted in streams after June seem unlikely to descend in numbers until the following year.

Since underyearlings are very susceptible to DDT poisining and larger parr less so, the size of fish to be used for rehabilitating streams in DDT-sprayed areas should receive consideration.

(5) *Type of bottom for planting stations.* It would seem advisable, where feasible, to plant fish in natural habitats. For young salmon this means in shallow rapids with gravel to rubble bottom rather than in deep pools.

(6) *Eels a danger.* Eels feed voraciously on newly-planted underyearlings. Therefore, planting sites should if possible be located away from areas of eel concentrations. Areas of large boulders and rubble in moderately swift water and pools are places where eels tend to be abundant. Eels are abundant in Bay of Fundy salmon streams, but apparently not nearly so plentiful in Gulf of St. Lawrence salmon streams. No generally feasible means of controlling eels has so far been devised.

(7) *Return of adults.* The value of hatchery-reared stock, derived from other streams, for providing adult salmon to the stream planted, needs further measurement. Hatchery-reared stock do, however, contribute to sea fisheries, even far distant from the stream of planting.

Acknowledgments

Hatchery stock was supplied and delivered on the requested dates to designated points, by the Fish Culture Branch of the Department of Fisheries. Throughout much of the work I was able to call on Mr. H. C. White for advice and assistance in field problems. The unstinting efforts of the Pollett field crew, headed at first by H. W. Coates and later by P. R. Graves provided much of the data on which these studies are based. I wish to acknowledge my indebtedness to all who assisted in any way.

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EDMOND CLOUTIER, C.M.G., O.A., D.S.P.
QUEEN'S PRINTER AND CONTROLLER OF STATIONERY
OTTAWA, 1958

Reprint from The Canadian Fish Culturist, No. 21, December, 1957, published by the Department of Fisheries of Canada, Ottawa.

Number of Salmon Needed to Maintain Stocks

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Most salmon streams obtain the greater part of their stock through natural spawning. How many fish must enter a river in order to keep up the stock? Such information can contribute materially to wise use of our Atlantic salmon resources. The number needed will depend not only upon the size of the river, but also upon how many young fish the river can raise by reason of its suitability for salmon, the abundance of predators and so on. Useful information on this problem is accumulating from research on the Pollett River, a branch of the Petitcodiac system, N.B., and on certain tributaries of the Miramichi River. This account is in the nature of an interim report pending accumulation of more complete data.

(a) HOW MANY SPAWNERS ARE NEEDED?

Experiments on planting hatchery underyearlings (Elson, 1957a) have shown how many young salmon one particular stream could support. The Pollett River could produce only five to six two-year smolts per 100 square yards of stream bottom. Such production could be obtained by planting underyearlings at the rate of about 35 per 100 square yards. This in turn should give about "10 large" parr, i.e. over 10 cm. or four inches total length measured from tip of snout to tip of tail (Elson, 1957b) which is the number required to assure the maximum production of smolts. Small salmon fingerlings, when first taken from a hatchery and liberated in a stream, do not live quite so successfully as native, wild salmon of the same size. But when they have lived in the stream for a year or more, they are probably equally valuable for producing smolts. So the question may be stated — How many adult salmon are needed to give large parr at a rate of about 10 per 100 square yards?

Studies are now being made of the numbers of underyearlings, parr and smolts produced by known numbers of adult salmon entering a 10-mile stretch of the Pollett River. The number of eggs brought into the stream is of more importance than the number of fish bringing them. Pollett salmon, most of which are grilse, weigh on the average, about $4\frac{3}{4}$ pounds. The number of eggs carried by female salmon tends to be in proportion to the weight of the fish. Pollett salmon carry 800 per pound of live weight. Hence it is useful to think in terms of the total weight of female salmon in the river, rather than their total numbers. In general, sex ratios and spawning habits of salmon are such that there tends to be a sufficient number of males for the females. The results which have accumulated from these Pollett observations to date are summarized in Table I.

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Table I

Underyearling and pre-smolt parr produced from known quantities of adults entering a 10-mile section of the Pollett River (25 yd. wide) based on seining in the same 10 sample areas each year. (a) Five to 15 per cent of large parr in the Pollett River are two-year-olds. This, or the limits of accuracy for seining could cause the discrepancy in the survival of underyearlings to parr.

Total weight of adult females		Potential egg deposition @800 eggs/lb. of female		Underyearlings in 1st summer		Large parr in 2nd summer		
Year	Pounds	Total number	No. per 100 sq. yd.	No. per 100 sq. yd.	Survival from eggs	No. per 100 sq. yd.	Survival from underyearlings eggs	
1953	210	168,000	38.6	2.2 (a)	6%	2.3 (a)	100%	6%
1954	390	312,000	71.7	5.9	8%	3.2	54%	4%
1955	310	248,000	57.0	4.0	7%	(in'57)	—	—

Using the results shown in this table, we can calculate that to get the 10 large parr needed in the Pollett for maximum smolt production will require, at the average survival rate of five per cent, potential egg deposition at a rate of about 200 per 100 square yards. This means about 44 pounds of female salmon (say 10 female grilse or four larger hen salmon) per mile of stream 10 yards wide. This is a general rate for the stream as a whole, not just for nursery areas or spawning beds.

In 1956 the average potential egg deposition in the same area was 252 eggs per 100 square yards. This last spawning will therefore provide a good test for the above hypothesis.

(b) DO MARITIME SALMON STREAMS RECEIVE ENOUGH STOCK?

There is strong public opinion that the Maritime salmon resource could be greatly increased by providing more very young stock, whether by legislating for greater spawning escapement, or by providing for greater distribution from hatcheries. The Miramichi is frequently referred to as a stream which should receive such benefits. For several years now, measurements have been made of the adult salmon runs into two Miramichi tributaries, and of the resulting populations of young salmon. The Northwest Miramichi has about 70 miles of effective salmon rearing water, which averages about 25 yards wide; the Dungarvon has 50 miles, and a similar width. Examination of adult salmon runs has shown the average size of the fish and the proportions of males and females. Records of the Fish Culture Branch of the Canadian Department of Fisheries show that, in general, as for Pollett fish, about 800 eggs are carried for every pound of female salmon. From this information it is possible to estimate the number of salmon eggs brought into these two streams—the potential egg deposition. The average annual figures are, for the Northwest Miramichi nearly 7½ million eggs and for the Dungarvon nearly 4½ million.

In Figure 1 potential egg deposition can be compared with resulting populations of young salmon as they advanced in age. All measurements are in terms of average numbers per 100 square yards of stream bottom. The values for young fish were determined by seining with electrofishing in several sample areas of each stream.

Tests have shown that the population figures for the sampling areas can be trusted to within about 20 per cent, ofter 10 per cent. Minor discrepancies in the figures given can be attributed to such error in counting the fish, but the general trends can be regarded as well established. For the Miramichi, nearly all small parr (10 cm. and under) are yearlings and over 90 per cent of the large parr (over 10 cm.), which will become smolts the following spring, are two-year-olds (Elson 1957b). For the diagram, parr have been allocated to years of egg deposition on the basis of size. Age analysis of samples, from studying scales, will doubtless result in minor corrections to the data.

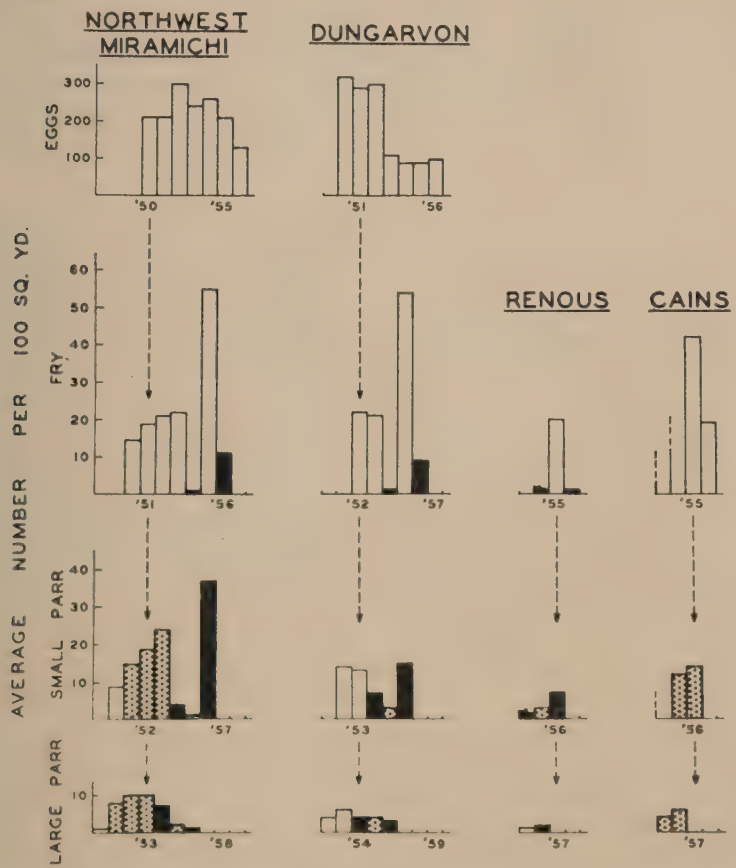

Figure 1.—Abundance of young salmon of various stages found in Miramichi streams by systematic population studies. Vertical arrows (↓) indicate survival between different stages of one year class. White columns (□) indicate abundance under natural condition. Dotted (▒) and black columns indicate abundance of groups affected by merganser control. Black columns (■) indicate abundance of groups subjected to DDT spraying as well as bird control.

Recall that in the Pollett River 10 large parr per 100 square yards were required to assure maximum smolt production. In the Northwest Miramichi similar numbers of large parr resulted from spawnings in 1949 and 1950 (Fig. 1). These two groups

received full benefit of merganser control; earlier groups did not and later groups were reduced as a result of spraying the drainage basin with DDT against an epidemic of spruce budworm (Kerswill and Elson, 1955). However, the two groups do provide evidence that the Northwest was then receiving a good supply of young stock. On the Dungarvon, full production of large parr was not realized in the absence of merganser control. However, underyearlings were as abundant as on the Northwest. Under natural conditions, potential egg deposition at a rate of 300 per 100 square yards did not produce many more underyearlings (fry) in these two streams than did potential egg deposition at 200. (Compare Northwest and Dungarvon in 1952 and Northwest in 1950 and 1951, in Figure 1.) Such a condition carries the implication that a potential egg deposition of 200 eggs per 100 square yards did not limit the production of young salmon in these streams. The Renous and Cains Rivers carried just as good stocks of underyearlings. (Fig. 1). This evidence indicates that the Miramichi has recently been receiving all the young stock that it can rear to more advanced stages.

How does the potential egg deposition in these streams compare with the calculated requirement of 200 eggs per 100 square yards made for the Pollett? The average for the Northwest has been about 235 and the Dungarvon 200; the weights of female salmon received by these Miramichi tributaries are respectively 52 pounds and 44 pounds per mile of stream 10 yards wide in comparison with the 44 pounds calculated to be required for the Pollett. There is some possibility that the Miramichi may not actually require as many eggs per 100 square yards as the Pollett in order to have the 20 underyearlings apparently necessary to give highest production of smolts. For one thing, eels have been found to prey on both salmon eggs and alevins still in the redds, as well as on older stages. But eels are only from one-tenth to one-twentieth as abundant in the Miramichi as in the Pollett. The average *natural* survival rate from eggs to fry found for the Miramichi (8 percent) was just as good as that found on the Pollett (7 per cent) with *very light* spawning. A very light spawning should give a maximum survival rate, since no excess over actual requirements is involved. In the Miramichi area, the lighter spawnings observed *did* give the best survival rates so some excess over actual requirements may well have occurred in the heavier spawnings.

During the period of these observations the Miramichi has received some plantings of underyearlings salmon each year. The Northwest Miramichi, has been planted with underyearlings at an average rate of 25 per 100 square yards for the whole stream. All plantings were actually placed in the lower 25 miles, which are accessible for hatchery distribution. Young salmon were most abundant in the upper 40 miles. On the Dungarvon, plantings provided underyearlings at an overall rate of six per 100 square yards; but all were liberated in the lower five miles of the stream because above this it is impractical to reach the river with hatchery products. Again, young salmon were relatively much more abundant in the upper part of the river. Thus the largest parts of these streams were not available to hatchery stocks (Elson 1957a). Most of the young stock must have come from natural spawning.

It does appear that several Miramichi streams have, in recent years, received sufficient young stock, mostly native, to produce many more smolts than they are now

doing. In fact, natural spawning has been sufficient to give maximum smolt production, if judged by standards developed on the Pollett River. It is hard to see how such streams could, *under normal conditions*, use to advantage more brood stock or hatchery products than they have recently been getting.

With the information at present available the best figure for the number of adult salmon required to maintain stocks can be set at "between 40 and 50 pounds of adult females per mile of stream 10 yards wide".

However, as shown in Figure 1, these young stocks are now seriously reduced as a result of spraying the adjacent forest with DDT. This chemical kills a high percentage of the young salmon. If spraying is to continue, natural spawning alone cannot provide a remedy since the young fry are most susceptible of all to the spray. Carefully planned use of hatchery stocks seems to be the one way of getting better production under these circumstances.

Acknowledgments

Much of the data used has been collected through the untiring efforts of the Pollett field crew, consisting of P. R. Graves, H. P. Barchard, L. MacFarlane and A. G. Steeves, of Elgin, N.B. Others assisted this group in the Miramichi seining studies. Dr. C. J. Kerswill provided data on Miramichi salmon runs. To these and all others whose assistance facilitated the work I extend my thanks.

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EDMOND CLOUTIER, C.M.G., O.A., D.S.P.
QUEEN'S PRINTER AND CONTROLLER OF STATIONERY
OTTAWA, 1958

Reprint from The Canadian Fish Culturist, No. 21, December, 1957, published by the Department of Fisheries of Canada, Ottawa.

The Role of Hatcheries in Assuring Maritime Stocks of Atlantic Salmon

by

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The abundance of Canadian Atlantic salmon as measured by records of catches has varied a good deal from time to time, even in "the good old days." Man has attempted to reinforce the stocks of these fish by artificial propagation of the young. Canada was one of the foremost countries in bringing such culture to a high stage of development. Our system for rearing young salmon and distributing them in suitable streams is one of the largest in the world.

Extensive distribution of hatchery-reared salmon in eastern Canada began about 1875. The early distributions were followed by large increases in the catches of salmon after the expected intervals, and in the proper districts (Wilmot, 1885). These increases were very welcome, following, as they did, right on the very lowest commercial salmon harvest on record, in 1881 (Fig. 1). Hatchery distributions continued to increase until they reached about 25,000,000 fingerlings yearly in the 1930's. Since then they have been reduced to around 10,000,000 to 15,000,000.

RELATION OF HATCHERY DISTRIBUTIONS TO CATCHES:

Have these widespread plantings had the notable effect on salmon harvests that was predicted in the 1885 report? If so, years of heavy planting should have been followed in due course by particularly good catches of salmon, and smaller plantings by smaller catches. For the Maritime Region (Cape Gaspé to the St. Croix River) most commercially caught salmon spend three years in rivers and two years at sea. The common interval from planting to harvest is therefore five years.

The sizes of hatchery distributions and corresponding catches in this region have been arranged diagrammatically in Figure 2. In the middle row vertical bars representing hatchery distributions between 1907 and 1947 have been arranged in descending order of magnitude. In the lower row bars representing commercial catches made *five years later* are arranged directly *under* their corresponding distribution bars. There is no clear resemblance between the patterns formed by the two different rows of bars. The conclusion seems to be that the contributions of hatchery plantings to the general salmon catches have not been large enough to show through the natural variations in these catches.

Hatchery distributions might be compared with commercial catches made *one year before* the distributions. Such catches represent, more or less, the availability of parent stock to the hatcheries. These catches are shown in the upper row directly

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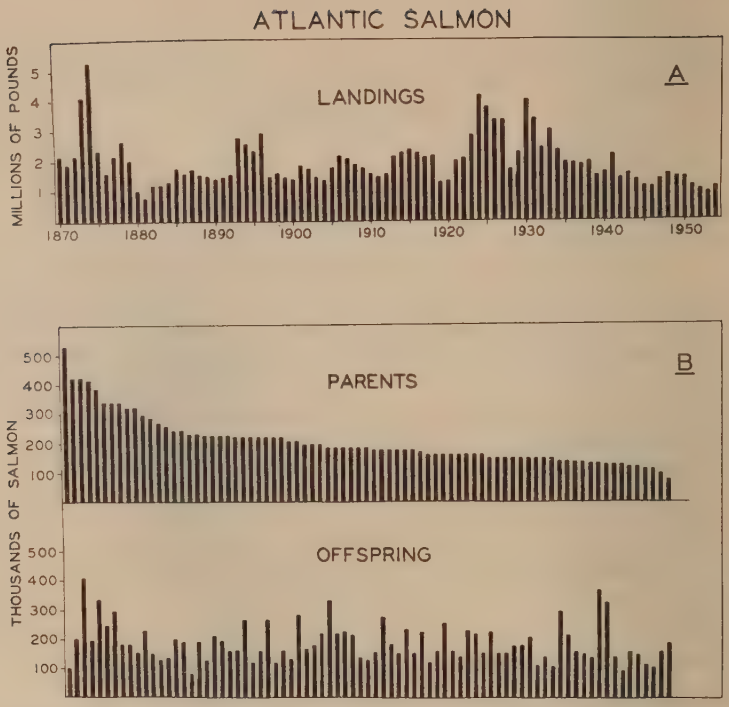

Figure 1.—Commercial landings of Atlantic salmon from the Gulf Area of the Maritime Region for 85 years. A. Annual landings in chronological order. B. Same catches plotted as numbers of 10-lb. salmon. Upper panel: numbers of parents in the first 79 years arranged in order of magnitude. Lower panel: numbers of offspring caught six years later, drawn directly below corresponding parent catch. There is no evidence of any relation between the size of catches from parents and the size of catches from their offspring. (Reproduced from Elson, 1955)

above their corresponding hatchery distribution. There is, in fact, a tendency for hatchery distributions to be larger in the years following abundant harvests of salmon. The relationship is obscured somewhat by a few particularly good catches; but the upper row of bars also tends to slope downward from left to right. It is quite logical that the hatcheries should be able to collect more eggs in years when mature salmon can be caught more readily. This is apparently what happened.

Both of the relations discussed above have been tested mathematically and the conclusions presented found to be valid.

As can be seen in Figure 1, there is no clear-cut relationship between the amount of parent salmon caught in one year and the amount of their offspring caught six years later (Elson, 1955). This can be interpreted as meaning that having a great many more salmon spawn in one year does not necessarily lead to an abundant catch of their offspring. Apparently naturally produced increases of young often do not show up in later catches. It should not be surprising, therefore, that artifically produced, smaller increases in young are not apparent either.

Thus the evaluation made in the 1880's of possible hatchery contributions has not been substantiated by later experience.

WHAT OUR HATCHERIES CAN CONTRIBUTE.

The fact that hatchery contributions cannot be identified by their effect on catches does not mean that they are not of value. In the last century practically nothing was known about the usual fate of planted fish. In the past quarter of a century considerable information on this subject has been collected. In those early years people

Figure 2.—Hatchery distributions of young Atlantic salmon arranged in order of magnitude (middle row) for comparison with commercial landings one year earlier (above) and five years later (below). There is a similarity of trend between earlier catches and distributions: this probably reflects availability of parent stock to hatcheries. There is no similarity between the trends for distribution and catches five years later when the planted fish should have made their biggest contribution to fishing: this indicates that hatchery contributions were not large enough to outweigh natural causes of fluctuation.

were pleased or worried over the status of salmon stocks according as recent catches had been good or bad (Perley, 1852) but there is no record of any attempt to estimate the total extent of Maritime salmon stocks. Now, as a result of researches made in the last 25 years, at least a rough estimate can be made. Thus it is now possible to place a better measurement upon the contribution which our hatcheries can make.

For this the first question to be asked is: How many mature salmon could be produced from 15,000,000 young salmon liberated each year by the hatcheries? It has been calculated on experimental evidence (Elson, 1957a) that with careful planning and management up to 15 per cent of hatchery-distributed underyearling salmon can be expected to survive to the smolt stage. Under adverse conditions the survival rate is liable to be only a fraction of this amount, perhaps around three per cent. Seaward-migrating smolts have been counted and marked in a number of instances, and their numbers compared to the numbers of returning adults. From these and similar studies it is found that, on the average, about eight per cent of the smolts (Table I)

Table I

Estimated survival rate of salmon marked as descending smolts based on reported returns to fisheries and counting fences in rivers; except Hayes (1953), which is based on estimates of total smolt production and total salmon associated with the river.

Place	Author	Survival rate
		%
LaHave, N.S.	Hayes, 1953	17
Margaree, N.S.	Huntsman, 1941	over 2
Miramichi, N.B.	Kerswill, 1957	5
Moser River (Mill Brook), N.S.	White, 1940	over 10
Moser River (main stream), N.S.	White, 1940	over 5
Moser River (Mill Brook), N.S.	White, 1941	10
Moser River (main stream), N.S.	White, 1941	9
Moser River (main stream), N.S	White, 1943	over 9
Apple River, N.S.	White and Huntsman, 1938	over 3
Mean survival rate and its standard error		8 ± 1.5%

survive the rigours of life in the sea and return to fisheries and rivers as mature salmon. Considering these survival rates, the yearly contribution of hatchery fingerlings could conceivably add about 180,000 adult salmon to the stock available for fisheries and spawning. This amount is roughly equivalent, in numbers, to the total take by commercial fisheries in the Maritime region.

MAGNITUDE OF SALMON STOCKS IN THE MARITIME REGION

1. Direct estimate from fisheries.

In order to evaluate the hatchery contribution we should develop at least a general idea of the size of the total stock. Our impressions of abundance are usually obtained from the numbers of salmon caught in fisheries. But how is catch related to actual abundance? There have been a number of studies in which salmon caught in nets, at sea or along the coast, have been tagged and immediately released again. Subsequent recapture of some of these fish leads to our best available estimate of the total

salmon stock. Table II gives the results from various areas. Applying the average value for recaptures (27 per cent) it appears that the combined commercial and sport fisheries of the Maritime region remove a little over one quarter of the salmon stocks available to the area. In recent years the commercial catch has amounted to around

Table II

Atlantic salmon tagged and liberated from commercial fisheries and recaptured in both commercial and sport fisheries.

Place of tagging	Number tagged	Total recaptures	Author
		%	
Petit Gaspé, P.Q.	100	38	Belding and Prefontaine, 1938
Sept Isles, P.Q.	80	9	
Rivière Nabissippi, P.Q.	43	28	
St. Augustin, P.Q.	63	6	
St. Paul P.Q.	150	29	
Port aux Basques, Nfld.	599	13	
Miramichi, N.B.	411	18	
Margaree, N.S.	758	13	Hayes, 1948
Margaree, N.S.	416	8	Hayes, 1949
LaHave, N.S.	192	28	Hayes 1953
Margaree, N.S.	100	25	Huntsman, 1939
Margaree, N.S.	161	26	
Margaree, N.S	267	25	
Saint John, N.B.	102	68	Huntsman, unpub.
Lorneville, N.B.	100	71	
Dipper Harbour, N.B.	102	31	
Total number tagged	3,644		

Mean rate of recapture and its standard error 27 ± 4.5%

150,000 salmon per season. The sport fishery in this region has been estimated to take 55,000 fish yearly, of which about one half are grilse (Kerswill, 1957). The grilse must be considered because they represent young stock which has survived to maturity just as much as larger salmon do. The total catch thus amounts to about 200,000 fish. If, as indicated in Table II, this is about one quarter of the available stock, there must be in the vicinity of 1,000,000 salmon available to the Maritime region. The rates of recapture listed indicate that it is unlikely that the total stock falls as low as 500,000 or exceeds 1,500,000 salmon in any one year.

2. *Stock size at various stages*

In order to appraise the usefulness of hatcheries, it is helpful to have estimates of the salmon stocks at various stages from eggs to adults. Estimates of this kind can be obtained from our data by using a slightly different chain of facts. The total catch by fisheries, say 2,000,000 pounds, is still used as the starting point. Also the proportion (27 per cent) that this forms of the total stocks as indicated by tagging results must be considered. Now let us assume that more fish are lost to seals, sharks, poachers and other causes of deaths in the sea and rivers, to the extent that only half of the total mature stock in the sea is left in the streams for spawning. As a matter of fact, Hayes' data for the Margaree (1949) shows not over 58 per cent of the counted,

available fish for the system being thus available for spawning. (He counted fish removed by the commercial fishery, fish entering the river and fish removed by anglers.) Using the 50 per cent figure, we should have close to 4,000,000 pounds of salmon available for spawning in Maritime region rivers. In general, half of these would be females. Female salmon carry about 800 eggs per pound of body weight. The survival rate from eggs, brought into one particular river, to fingerlings the following summer has been established as about 5 per cent when there is no excessive spawning (Elson, 1957b). Using these figures, Maritime salmon streams, as a whole, are now receiving natural stocking at the rate of about 80,000,000 salmon fingerlings per year. Information now accumulating indicates that under favourable conditions, which include protection from excessive predation by mergansers, one-quarter or more of these fingerlings can survive to the smolt stage. These smolts, granting an 8 per cent survival rate over their sea life (Table I) would contribute a little over 1,500,000 salmon to the stock available for fisheries, spawning, etc. This second estimate is of the same general order as that obtained by a slightly different chain of thought, above.

The tagging studies referred to in Table II were made in areas of relatively important fisheries; and of course only salmon which had already entered the fisheries could be tagged. There are considerable numbers of salmon associated with small streams where fisheries are less intense. There are also many salmon which apparently do not reach fishery areas during open seasons; for example, the extensive autumn runs of the Miramichi system. To the extent that the tagging studies take no account of such fish the estimate of total stock given above is too low. However, plans for reasonable exploitation and conservation of the stocks based on low estimates are quite unlikely to damage our salmon resource.

Discussion

The potential value of the annual hatchery contribution might be evaluated on the basis of (1) 15,000,000 hatchery fingerlings added to the native stock of around 80,000,000 native fingerlings; or (2) 180,000 mature salmon added to the sea stock of about 1,000,000 fish; or (3) 50,000 salmon added to the 200,000 taken by fisheries. However assessed, the potential contribution seems to be of the general order of one-fifth to one-quarter of the present stock.

An addition of 500,000 pounds (commercially caught salmon average about 10 pounds weight) to Maritime region catches is a valuable contribution. But, spread over the entire region, it could scarcely be identified in catch statistics of a fishery which has fluctuated from under 1,000,000 to over 5,000,000 pounds per year during the last 80 years. This explains, at least in part, why the value of hatchery contributions does not show in such an analysis as is illustrated in Figure 2. However, an additional catch of 500,000 pounds divided among a few smaller fisheries could make a very evident contribution to these.

In the same way, an increase in general spawning stock of 75,000 to 100,000 salmon would scarcely be noticed by its effect. But this is enough salmon to completely stock a number of small rivers, or even one fairly large system. As an example, an

annual run of 3,000 to 4,000 grilse and salmon combined appears to provide good angling and sufficient spawning stock in the 70-mile-long Northwest Miramichi River.

Thus Canada's hatchery system for Atlantic salmon can add a valuable amount to Atlantic salmon stocks. But even more important, it is a resource which can ensure against extinction of stocks if and when this should threaten.

The professional fish culturist, alone, is likely to have ready access to the background of facts which are necessary in order to make a sound decision about where and how hatchery stock can be used to best advantage. He must first get some clue as to why fish are scarce. Could it be simply that weather and water conditions were not right for getting the salmon into fishery areas? Or are young salmon really scarce in the nursery streams? If so, are they scarce, from the very youngest stages up, or only the older stages? What are the conditions that face the different stages of young in any particular stream? To be most effective, hatcheries must be able to add fish to replenish the stage at which native fish are scarce in the stream. Hatcheries are not designed to remedy shortages by supplying excessive stock in advance of depletion and regardless of the cause. These are the sort of problems that must be considered in order to get the most out of hatcheries for Atlantic salmon. Whenever well-considered answers can govern their procedures, hatcheries provide, over the years, a means of bolstering and restoring damaged fisheries; of revitalizing fisheries which have nearly or entirely disappeared; and even of creating new stocks for new fisheries. But if uninformed demands or other circumstances govern their procedures, our hatcheries can, at best, hope to add only about one quarter to the value of the general salmon harvest. No contribution of such magnitude could be positively identified in catch statistics.

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QUEEN'S PRINTER AND CONTROLLER OF STATIONERY
OTTAWA, 1958

REPORT ON POLLUTION STUDIES CONDUCTED IN WESTERN CANADA*

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I. Industrial Pollution

Emphasis in pollution studies in British Columbia has been on the industrial development of forest product industries. There are at present eight pulp mills on the B. C. coast, four of which are undergoing expansion. One new pulp mill is being constructed, and at least two new pulp mills are in the embryonic stages of planning. Characteristically large water users, pulp mills can be a major source of water pollution. The research work has been closely coordinated with the supervisory branch of the Department of Fisheries, which receives the requests for approval of plans for waste discharge from industry. The policy that "prevention is more effective than abatement" has been continued, and pollution problems are carefully assessed before they occur. In most instances an effort is made to draw on existing data and knowledge in these studies, inasmuch as it is not desirable to hamper industrial development by delays of long-term research. Where additional survey data or bioassay information are required, these are taken as facilities and manpower permit.

From the point of view of economy and lower pollution, new pulp mills are installing equipment for production of Kraft (sulphate) pulp as opposed to the sulphite process. The Kraft process permits reclamation of the salts in the "black liquor" by evaporation and burning of the organic material. ("Black liquor" is the dark brown fluid which results from the cooking of wood chips in an alkaline solution at about 330°F under pressure in a digestor). Any of the liquor which escapes in the wash from the screens is generally too dilute for economical recovery. It is this wash water which constitutes the major pollution hazard from a Kraft pulp mill. Sulphite digestion is predominantly used in the older pulp mills. An economical recovery process for reclamation of the salts in sulphite waste liquors has not yet been perfected for wide use. In general, effluent from a given tonnage of sulphite pulp produces about 10 times as great a pollution hazard as that from an equal tonnage of Kraft pulp.

Newsprint mills contribute a relatively small pollution. The mechanical grinding of wood in groundwood mills results in a discharge of wastes contaminated only by sap, bark extracts, and fibres from the wood. Most of the pollution stems from the oxygen demand of the organic constituents during decomposition.

The major factors which are responsible for the harmful aspects of pulp mill wastes to fish are:

*Reprinted from pages 188-194 of report on *"Biological Problems in Water Pollution"*, U.S. Department of Health, Education and Welfare, Bureau of State Services, Division of Sanitary Engineering Services, Cincinnati, Ohio, 1957.

(1) Biochemical oxygen demand

(2) Direct toxicity

(3) Destruction of food organisms

Analysis of pollution problems with respect to Kraft mill effluent has shown that where dilution is sufficient to combat the B. O. D. (biochemical oxygen demand) of the waste, direct toxicity is only secondary. Bioassay studies conducted at this Station show that concentrations greater than 4.0% of Kraft mill effluent are toxic to young sockeye in sea water for periods greater than one week (Brett and Alderdice, 1954). No research has been pursued on the effect of Kraft mill effluent on fish food organisms. There has been no evidence of a severe reduction in plankton and benthic fauna in regions of British Columbia where pulp mill wastes have been discharged.

There have been three basic types of marine systems on the B. C. coast where pulp mill pollution conditions have had to be studied.

A. Inlet-type - Numerous pulp mills in British Columbia are located at the head of an inlet, often adjacent to an estuary. The choice of such a locality stems from the availability of good forests nearby, ease of transportation of logs from inlet logging regions, fresh water supply, hydroelectric power, and favourable harbour facilities. As a hazard to anadromous fishes these pulp mills require the greatest precaution in effluent disposal. Wastes passing into estuarial waters come directly into the path of migrating salmon. A severe case of pollution might completely wipe out a salmon run.

Evaluation of the capacity of an inlet system to receive wastes according to oxygen supply and dilution has been based on the study of Tully (1949) on Alberni Inlet. Waters from runoff undergo a continuous displacement seaward. The use of the fresh water as a tracer to determine the movement and mixing of effluents has permitted prediction of pollution with varying pulp production. Being of about the same density as fresh water, pulp mill effluent mixes only in the surface brackish layer. Thus the most effective control on the extent of pollution in an inlet-type condition is (1) controlled discharge of fresh water above a certain minimum flow, (2) release of the effluent at the surface and (3) maintenance of the effluent in the jet stream of the surface flow.

The problem of pulp mill effluent discharge in volumes above the safe capacity of natural receiving waters was met in the expansion plans of the Port Alberni pulp mill. Present production of 230 tons of unbleached Kraft pulp, established on the basis of Tully's (1949) work, does not impose an excessive pollution load on the inlet. The effluent can be flushed effectively from the inlet by the natural tidal conditions and Somass River discharge. But the expansion to roughly 500 tons of Kraft pulp and about 500 tons of newsprint per day would impose an oxygen demand on the inlet system in excess of the natural supply. This is particularly true with the reduced river flow during the late summer. A stream which normally fluctuates from about

Figure 1. Chart of the British Columbia coast showing existing and proposed pulp mill locations.

300 c.f.s. in September to peaks of 30,000 c.f.s. in November, the Somass River must be maintained at a discharge of 1,000 c.f.s. or greater to overcome any serious pollution from the proposed mill.

B. Coastal Seaway type - In this type of location, effluent is discharged directly into a seaway, use being made of tidal currents and mixing to remove and disperse the wastes rapidly. There is seldom any estuary adjacent to such pulp mill locations so that fisheries of salmon or trout are not likely to be endagered. At the Harmac (Nanaimo) pulp mill, effluent from a daily production of 600 tons of fully bleached Kraft pulp is discharged into Northumberland Channel. Tidal currents here are predominantly southbound (ebb) reaching a knot on certain stages of the tide. The geography is such that little of the effluent reaches the vicinity of Nanaimo Harbour, but is rapidly funnelled into the turbulent waters of Dodds Narrows. With currents commonly over 5 knots strength, pulp mill effluent is completely mixed into the sea water in Dodds Narrows, no traces being detectable below the narrows.

Other examples of this type of effluent discharge can be seen at the Duncan Bay (Campbell River) pulp mill and at Powell River. Duncan Bay, located on Discovery Passage, is relieved of its effluent by the strong tidal currents (up to 7 knots) just south of Seymour Narrows. Powell River discharges effluent into more quiescent waters of Malaspina Strait and Algerine Passage. No evidence of pollution has been reported in either region. Popular sport fishing for salmon is especially renowned at Campbell River.

Any pollution which could arise in these cases in future expansion would probably result from an adverse effect on migrating juvenile salmon. In Discovery Passage large schools of young salmon seek the shelter of the bays and inlets in their journey to the sea. It is hoped that observations can be made on the effect of expansion of the Duncan Bay pulp mill on the young salmon passing through the bay during the summer.

C. Restricted Embayment type - Being intermediate between the inlet-type condition and the coastal seaway, the restricted embayment does permit some flushing by virtue of its openness to an adjoining channel. Generally, however, it possesses a circulation all its own independent of that in adjoining channels. Hence a certain amount of stagnation results.

The pulp mill at Port Edward near Prince Rupert is an example of this type of situation. Shallow, restricted conditions in Wainwright Basin and Porpoise Harbour hinder the flushing of the effluent into Chatham Sound. Large concentrations of mill wastes have been particularly evident during low tides. Mixed reports have been received on the effect of the wastes on the biotic environment. Some observers have reiterated that all marine life in that vicinity is being destroyed. But observations carried out by biologists of the Department of Fisheries (May, 1953) claim that these reports are exaggerated, and that both fish and bottom fauna appear to prevail in normal health. A further investigation of the region is planned in the near future from the Biological Station, Nanaimo.

The proposed pulp mill at Crofton will create another sample of a pulp mill in a restricted embayment. Osborn Bay, into which the effluent would be normally discharged, is relatively sheltered from Stuart Channel; its flushing and circulation are sluggish. The bay is fringed, particularly at the northern end, by oyster-growing leases. Living primarily in the intertidal zone, oysters are vulnerable to any harmful wastes found in the surface waters. In order to prevent the lost of oysters entirely, action would have to be taken to discharge the effluent outside the oyster-growing area or render it innocuous by treatment. The most satisfactory solution to industry economically was the piping of mill wastes into deep water (10 fathoms) in Stuart Channel beyond the Shoal Islands protecting Osborn Bay. Recommendations have been made to this effect and have been met with agreement by both the Provinical Department of Fisheries, Federal Department of Fisheries and Industry.

II. Domestic Pollution

A limited amount of work has been conducted on pollution from domestic wastes in coastal communities of British Columbia.

A. Vancouver Sewage Disposal

Study of the effects of sewage disposal from Vancouver was undertaken as a cooperative effort by the Pacific Oceanographic Group, National Research Council, Institute of Oceanography of the University of British Columbia, Tidal Branch of the Hydrographic Service of Canada, and Air Surveys Branch of the British Columbia Department of Lands and Forests at the request of the Vancouver and Districts Joint Sewerage and Drainage Board. Oceanographic data were collected seasonally in the Fraser River estuary and in Vancouver Harbour over a period from September, 1949 to March, 1951.

Preliminary analyses of these data along with tidal current information and aerial photographic surveys have been used for establishing the circulation in Vancouver Harbour and at the Fraser River estuary. These studies showed how the tides and discharge from the Fraser River combine to produce a characteristic circulation in Burrard Inlet.

Off Point Grey, there is a predominent northward set of the current into English Bay on all stages of the tide. Off Point Atkinson, at the northern shore of the entrance to Burrard Inlet, there is a prevailing westward current out of English Bay. A counterclockwise main eddy system with numerous smaller eddies and stagnation points superimposed on the principal circulation were noted to exist in English Bay.

The results of the oceanographic studies have permitted the evaluation of different outfall points for their suitability in sewage disposal. Final choice of discharge locations was based largely on the effectiveness with which the sewage would be dispersed and removed by the currents.

B. Nanaimo Harbour Sewage Disposal

An oceanographic study of currents in Departure Bay and Nanaimo Harbour was conducted as a cooperative venture between the Pacific Oceanographic Group and community groups of the city of Nanaimo. A large measure of assistance was given by the Nanaimo Yacht Club with their boats, and much volunteer help came from the Nanaimo city employees. Close cooperation was maintained with the local branch (Central Vancouver Island Health Unit) of the Provincial Department of Health and Welfare. The prime concern in the survey was the determination of existing pollution from a health standpoint and further contamination of beaches to be expected from additional sewage discharge.

Results of the survey indicated that Nanaimo Harbour is already polluted by existing sewer outfalls and that beaches within the harbour are not fit to be used for bathing. Departure Bay beach is still free from contamination, but is threatened by any sewage discharged at Brechin Point (located at the northern end of Newcastle Island Channel between Nanaimo Harbour and Departure Bay). Surface currents in both bays are largely wind-driven. The prevailing southeasterly winds would drive any increased sewage output into Departure Bay and gradually wipe out the remaining beach recreational area in the district.

Recommendations were submitted to the City Council of Nanaimo that either the sewage be totally treated before discharge, or it should be piped beyond the barrier islands (Newcastle and Protection Islands). These recommendations are being acted on at present and further survey work is awaited to determine the most appropriate discharge points outside the islands

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Transport and Storage of Fish in Refrigerated Sea Water

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THE origin of this method is a little uncertain. The first literature reference appears to be a French patent assigned to LeDanois in 1920. However, his claim covered holding fish on boats at 4°C. (24.8°F.) in sea water or brine, a treatment which would obviously freeze the fish. Active work was carried out at this Board's Halifax Station around 1928-1931 by Huntsman and by Ness. It was shown that the "freezing point" of fish muscle was about 30°F., a temperature which could be attained in practice by simply using circulating sea water containing ice. Fish kept twice as well at this temperature as at about 35-37°F. Like many other things which fishery researchers have suggested, the finding was apparently regarded as purely academic and it was not until 1947 that from our station an article entitled "Preservation of quality of edible fish products" was published in which the following statement was made: "Clean sea water (or a 3% salt brine) cooled with crushed ice or by other means will have a temperature of about 29°F. and might be of value in fish wells similar to the refrigerated brine wells used in tuna boats". A few years later small-scale trials were made on salmon trollers with very encouraging results.

The period 1954-1956 was one of really active experimentation in which all Station divisions collaborated. The biochemistry group undertook tests to determine salt penetration employing a sensitive flame spectrophotometric method. Interesting comparative investigations concerning colour in salmon, development of "belly burn" and weight changes in fish stored in ice and in refrigerated sea water were carried out in the chemistry department. In the microbiology division bacteriological studies were conducted in order to evaluate the effect of chlortetracycline (Aureomycin) in preservation of fish stored in chilled sea water and in ice.

Engineering

Though fish may be stored in refrigerated sea water in a simple tank with ice and a water-circulating device, it is obvious that mechanical applications on sea and ashore require proper engineering studies. Thus insulation, corrosion prevention, selection of appropriate power supplies and compressors, and even the study of unloading devices are involved.

The work on the practical application of refrigerated sea-water fish storage on vessels has had a cautious but steady development. Installations were made on commercial vessels to prove the economic feasibility of the system, as well as to prove that it maintains the desirable quality of fresh fish longer. Early experiments were made on small salmon trollers. Metal or plywood tanks were installed in the hold. Cooling coils were mounted in a compartment of the tank to permit circulation of the water by pumping over the coils and through the fish. The compressor was driven mechanically from the main engine. These early experiments proved several important points in further development of the system. Firstly, that fish handled in regular fishing operations by fishermen rather than under laboratory conditions could be held in good condition for periods of at least 14 days. Secondly, it proved that large quantities of fish (about 50 lb. of fish to 1 cu. ft. of water or 80% of the total tank load) could be handled, and that there was still adequate passage between the fish for sea-water circulation for cooling. Thirdly, it proved that the main engine as

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Dr. H. L. A. Tarr carrying out analytical procedures.

motive power for the refrigeration compressor was practical in fishing vessels.

The first large experiment was the equipping of the B.C. Packers fish packer "J.R.D." with a system designed to hold about 50,000 lb. of fish, funds being provided by the Industrial Development Service of the Department of Fisheries. The purpose of the experiment was to obtain data for design and operation of relatively large systems, and to find if this method of storage was practical for packers where conditions of receiving, stowing and transporting fish were quite different from those on trollers. The "J.R.D." is a wooden vessel 60 ft. long with a single hold forward of the engine room and deck house. Three tanks were fitted into the hold, a transverse tank forward, and wing tanks on either side aft of it. The three tanks were shaped to fit the hold. A trunk aproximately 4 by 5 ft. with gasketed hatch lid extended 1 ft. above the deck from the top of each tank. When in operation, the tanks were kept filled to within 6 inches of the top of the trunks. This arrangement substantially reduced the free water surface subject to movement in the tanks during rolling or pitching of the vessel, and thereby prevented surging of the fish in the tanks or surging effects of the tanks' contents which could affect the stability of the vessel. The tanks were of welded construction made from ¼-in. Alcan B54 SF aluminum plate which was selected for its strength, welding properties and resistance to sea-water corrosion. External stiffeners of 2 by 2½ by ¼-in. aluminum angle were spot-welded to the tank sides. Two inches of cork insulation was applied to the external tank surfaces. Cooling coils were installed in a compartment in each tank. They were fabricated from Alcan 1 SF extruded tubing ¾-in. O.D. and each coil had four banks with 60 ft. of tubing in each tank. Originally all mechanical equipment was mounted on deck as the installation was experimental and removal of the equipment had to be considered. After its first season's operation the equipment was relocated in the engine room and integrated with the ship's equipment. In the final arrangement the refrigeration compressor was V-belt driven from the ship's auxiliary engine. The compressor was a 7½-h.p. Freon 12 model, delivering 70,000 b.t.u. hr. at 20°F. suction temperature. The condenser was a water-cooled marine cleanable type, its cooling water being supplied by a self-priming centrifugal pump V-belt driven by the auxiliary engine. Circulation was provided in each tank by a 1½-in. centrifugal pump for each tank electrically driven from the ship's 32 V DC supply. A shell and tube chiller was mounted on deck to provide rapid cooling of any one tank. It was served by the single compressor which supplied the cooling coils in each tank.

The main points proven by this experiment were that the method is practical for packers; that tanks of this size can be operated satisfactorily with respect to circulation, loading and unloading and sea worthiness of the vessel; and that direct mechanical drive of a single compressor satisfies the requirements of a packer.

Our next experimental application was designed to investigate the application of refrigerated sea water to halibut fishing where the long holding time required due to the length of the trip dictates some improvement in holding methods. A halibut trip consists of 12 days average fishing time plus 1 to 5 days returning to port, plus 1 to 5 days in port prior to unloading.

The vessel selected for this experiment was the "Silver Viking" which was being built, thus making possible the incorporation of the system into her original construction. Funds for the installation were provided by the Industrial Development Service of the Department of Fisheries. Since this vessel was designed as a combination salmon seiner and halibut longliner, it also made possible a study of the application of refrigerated sea-water holding to salmon seining. The vessel is a typical Pacific salmon seiner of wood construction, 78 ft. long with a 22-ft. beam. Six tanks were installed in her hold, three on either side of the shaft. The tanks were constructed of 3/16-inch steel plate and surfaces unsupported by the hold lining were stiffened by 2½-in. angle irons toe-welded on 2-ft. centres. The inside surfaces were coated with an Epoxy-resin coating to resist corrosion. Two inches of cork insulation were applied to the external surfaces.

Mr. J. S. M. Harrison checks the newly designed heat exchange unit for chilling and maintaining low temperatures in sea-water tanks.

Cooling coils, located in each tank, were made of 250 ft. of ¾-in. O.D. steel tubing, the assembled coil being hot-dip galvanized. The coils were contained in closed compartments along the inboard tank sides. Circulation of the chilled sea water was provided through this compartment by a separate circulating pump for each tank. Refrigeration to these coils was supplied by two compressors, one for the three port tanks and one for the three starboard tanks.

To augment this refrigeration

system there was a completely separate one comprising a shell and tube chiller installed, as with the "J.R.D." circulating pump and refrigerant compressor. This system was used to speed up the initial cooling of any one tank but also served as a stand-by system in event of failure of the tank coil system. All pumps and compressors were electrically driven. Power was supplied by two diesel-driven alternating-current generators. These generators were the 120-208-volt type which supply either single phase 120-volt current for the small motors and ship lighting or 208-volt 3-phase power for the larger motors.

Of special interest in this project was the chiller which as explained previously was designed to assist in the initial cooling of the sea water and to a limited extent to act as an emergency system. However, since the first purpose was of greatest importance, the chiller was designed with a close tube spacing permitting high-water velocity and hence a high heat transfer from the tubes. Thus, a chiller of small outside dimensions which could be easily installed or dismantled for maintenance could be made. It was not expected that this design would permit attaining low temperatures because of ice formation on the tubes. This, however, was not the case as it has proven possible to cool water to 30°F. with the chiller.

The chiller has an outer shell of 6-in. Kralastic pipe. The use of this material serves three purposes: it reduces the weight of the chiller; eliminates corrosion of the shell, and provides sufficient elasticity to prevent rupture by freeze-up. 240 ft. of ½-in. O.D. copper refrigerant tubing are contained in the shell and arranged for dry refrigerant expansion in six parallel circuits of four horizontal runs of tubing extending the length of the shell. Twenty semicircular baffles direct flow of sea water across the tubes. All refrigerant connections are on one end to permit easy removal of the shell for maintenance.

The success of this chiller has altered our opinions on design of refrigerated sea-water equipment. With such small chillers being

Loading crabs into chilled sea water.

effective they can be relied on entirely for the cooling without employing tank coils. This change would in turn affect other components of the system. For example, on such an installation as that of the "Silver Viking" the same flexibility and guarantee against failure could be obtained with two compressors and two chillers as is now afforded by three compressors. Similarly, two compressors could be driven mechanically as in the "J.R.D." installation, whereas a third compressor warrants electrical generating and driving. The removal of coils from the tanks would simplify maintenance and permit the use of cheaper corrosion resistant coatings.

Weight changes. It has long been known that whole fish (or for that matter isolated fish muscles) undergo marked weight changes, which involve weight increases under some conditions and losses under other conditions. Fish immersed in water, or stored in top layers of ice, undergo weight increases which may amount to about 3%. In refrigerated sea water fish also gain in weight and losses have not so far been observed. This is not surprising in view of the published information which is available concerning effect of sodium chloride on "swelling" of fish muscle tissue. The situation regarding weight increases in fish stored in chilled sea water is quite complicated, for factors such as salt concentration in the sea water (in our coastal waters the salt content is very variable), size and fat content of fish, whether fish are eviscerated or not and the storage period, all play a part.

In studies with eviscerated and round immature coho ("blueback") and sockeye salmon weight increases after six days in refrigerated sea water varied between 0.2 to 3.7%. With small fish such as soles much larger weight gains (e.g. 20%) have been observed under exaggerated conditions. With herring it was found that greater weight increases occurred when sea water was diluted to half its natural strength, and that when the fish were immersed in a solution containing natural "body levels" of potassium and sodium ions (isotonic concentrations), the fish gained 7.7% in one week. In ordinary sea water they gained 3.5%. Attempts are being made to control excessive weight increases in fish stored in refrigerated sea water. In general it is felt that the weight increases encountered with normal holding times with most fish are not excessive and should certainly not be of undue concern when the normal improvement in quality which usually occurs is taken into consideration. They are usually no greater than those occasioned by fillet "brining" procedures.

Salt penetration. The distribution of K^+ (potassium) and Na^+ (sodium) ions in fish flesh has been established for a number of British Columbia species, and it varies with

such factors as size of fish and sexual condition. In general, within limits of around ± 20% marine fish have about 500 parts per million of Na^+ ions and 4000 p.p.m. K^+ ions. Studies have indicated that for about the first day in refrigerated sea water the Na^+ and K^+ ion content is approximately unchanged and that thereafter there is a slow increase in Na^+ ion content for about three weeks. As an example, with dressed small coho salmon with an initial Na^+ content of 550 p.p.m. (equivalent to about .14% ordinary salt (sodium chloride) the following Na^+ (as salt) contents were observed: 1 week, 0.95%; 2 weeks, 1.3%; 3 weeks, 1.8%; 4 weeks, 1.5%. The K^+ decreased to about one-quarter the initial concentration. The salt content after two weeks would be certainly no more than that found in normally canned salmon. There was no indication that holding fish in potassium chloride solutions instead of sodium chloride solutions changed appreciably the general total inorganic ion levels in the flesh. Only a few figures were obtained for medium halibut stored two weeks or more in refrigerated sea water but these, and taste tests by a number of individuals, showed that the "salt content" was not high enough to affect taste adversely. It is planned to carry out more detailed tests with halibut during the coming season.

Nitrogen (protein) losses. The only work so far completed has been that with sockeye and coho (blueback) salmon. Fish were stored in refrigerated sea water at a ratio of fish: sea water of 3 to 1. In general it was found that eviscerated fish lost more protein than did round fish. Thus after six days in sea water 3.25% of the flesh protein was found in the water with dressed fish, and 1.25% with round fish. Where the round fish were held in a relatively large volume of sea water (where the ratio of fish to sea water was 1 to 10), 3.0% of their protein occurred in the water. Round sockeye salmon stored in ice for 7 days lost 2.5% of their protein and 2.5% weight. Thus round iced fish appear to lose more protein than do those stored in refrigerated sea water.

Autolysis (belly-burn). On the B.C. coast some fish are not eviscerated on the fishing vessels. This is due either to the comparatively low prices offered for fish such as "soles", gray cod, "sea bass", herring, etc., or the rather short storage periods such as prevail in certain salmon fisheries. Naturally this system as it pertains to fish destined for human consumption should be strongly discouraged, especialy where it is also used without icing or with very inferior icing procedures. Where fish are not "feedy", are well iced and are not stored for many days, it would appear that not a great deal of harm results. With feedy fish and high storage temperatures there can be, and frequently is, extensive damage, and this is probably largely due to post-mortem bacterial and digestive enzyme activity which may increase around 100-fold in feedy fish. Progressive people in the fishing industry look forward to the day when these handling defects may be overcome and it is for this reason that some initial trials were made to ascertain the effect of refrigerated sea-water storage on "belly-burn".

With round blueback (coho) salmon which were very subject to belly-burn this change was delayed for up to three days when the round fish were stored in refrigerated sea water, but after this time belly-burn occurred to a pronounced extent. Sockeye salmon which were not subject to belly-burn were stored "round" for six, and in some cases 14 days in refrigerated sea water without any serious adverse effect.

"Curd" in canned salmon. It has long been known that a protein "curd" often forms in salmon during canning, and that this condition is accentuated when thawed frozen salmon are used, and may be alleviated by certain treatments such as light brining or treatment with tartaric or phosphoric acid. The work on refrigerated sea water has shown for the first time the long-suspected fact that there is a definite correlation between increased post-mortem age of salmon and curd formation. Comparative studies with blueback salmon have shown that there is considerably less curd formed with fish stored in refrigerated sea water than with those stored for a comparable time in ice. Wide and as yet unpredictable variations in curd formed in fish from different localities have been found. Extensive studies carried out during the past season have shown that curd formation can be very actively suppressed by an appropriate tartaric acid treatment.

Microbiological observations. We have carried out quite extensive studies on bacteriological populations of fish stored in refrigerated sea water as compared with those stored in ice, and the effect of chlortetracycline on these populations. At the moment we are actively conducting studies which have been designed in order to compare the three important tetracycline antibiotics for these purposes. It is important to emphasize that one is dealing with quite different systems with chilled sea water and with ice. With the former we usually deal with a static volume of liquid of relatively constant temperature (30°F.), with the latter we have higher temperatures (32-38°F.), but the fish are being "washed" slowly with ice-cold water, and bacteria are undoubtedly being washed away. It might be argued that the sea water should be changed occasionally; however, this is not desirable because of the necessity of keeping the temperature low and because constant admittance of fresh sea water may cause too high salt uptake by fish.

In our experience eviscerated fish can very often be stored at 30°F. in sea water for two weeks with no antibiotic and no important bacterial spoilage. On the other hand there have been times when very slimy and heavily contaminated fish have been stored for lesser periods under these conditions and the water has had a very unpleasant odour. Thus there is danger of spoilage, and the introduction of a little chlortetracycline (e.g. 1 to 5 p.p.m.) overcomes this, and one has an excellent storage system. Halibut and eviscerated coho salmon have been kept about *1 month* in refrigerated sea water with a trace of chlortetracycline and they have still been in quite good edible condition.

Storage and Transportation Of Frozen Fish*

Fisheries research indicates that lower temperatures should be used in the transportation of frozen fish. Also, loading and unloading practices should be improved so that the frozen fish are not allowed to warm up.

by Dr. W. J. Dyer

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Today, some of the results obtained on the studies of storage conditions in relation to their effect on quality of frozen fish being conducted at the Fisheries Technological Station at Halifax will be discussed.

To begin with, we asked ourselves if there is any deterioration in stored frozen fish products. Presumably, the ideal frozen product should reach the consumer in a condition as fresh as when it was first caught. Almost any consumer of frozen fish will agree that this ideal is not often realized in practice.

The next question was — what changes occur, and how may they be prevented?

"Freezer Burn"

The first obvious change in frozen fish is dessication or "freezer burn". This is due to loss of moisture from the surface and results in a dry papery surface which will not reconstitute to a palatable product on cooking. These changes may be prevented by glazing in the case of some products, and by moisture-proof wrapping in the case of fillets and packaged products. In subsequent discussion, we will assume that this problem has been adequately taken care of.

Freezing to temperatures below about 20°F. effectively stops bacterial activity, so that the fresh fish spoilage changes are prevented during frozen storage. Most enzyme activity, or autolytic changes, is also stopped on freezing, with the significant exception of some of the fat-splitting enzymes.

What changes then do occur on frozen storage? To answer this question, a taste panel was set up at the Station, with the object of tasting and grading the cooked product prepared from fish which had been stored under various conditions. At first, the object was to find in what specific ways the quality of the fish changed on storage, and later grading was undertaken.

Changes In Quality

Two important findings emerged from our initial work on frozen cod and haddock fillets.

First, the initial changes in quality were concerned with texture. This gradually became tougher, and chewiness and dryness developed. The taste panel score gradually decreased on storage of the fish almost to inedibility.

Second, after the first was nearly complete, off-odour and off-flavour development was noted. This was characteristic of fat spoilage, and was often described as a "salt fish taste".

The next step was to find out what caused these changes. After considerable work, it was found that one fraction of the protein, actomyosin, which constituted about 75% of the total protein was becoming insoluble on storage. White fish muscle contains about 81% water and about 16% protein. When this protein fraction becomes denatured or insoluble in salt solution in which

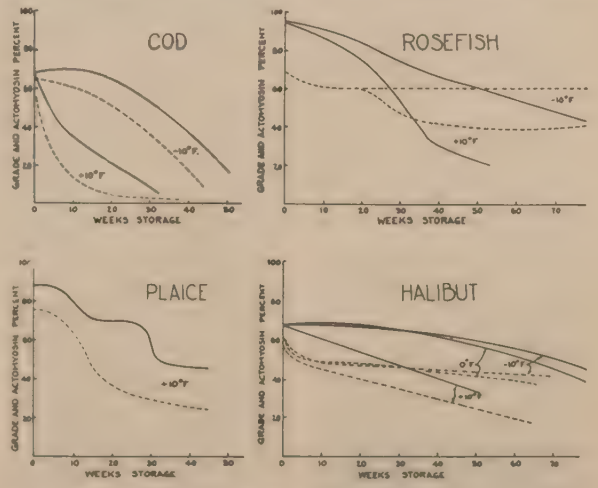

Fig. 1. Taste panel grades, 0 - 100% (solid lines), and extractable actomyosin (dotted lines) as percent total protein in frozen fillets stored at 10°F., 0°F., and at -10°F. (Diagrams drawn by Dr. Dyer.)

* Presented at the Annual Meeting of the Fisheries Council of Canada, Montebello, P.Q., April 26, 1957, and reprinted with permission from *Canadian Fisherman*, June 1957, pages 37, 39, 41, 43.

it dissolves when in the native state, it also loses some of its ability to combine with and hold the water in the tissue. Thus, the tissue becomes tougher and eventually unpalatable. The solubility of the fish muscle protein in 5% salt solution under certain conditions is thus a good measure of the degree of protein change.

The development of the off-flavours was obviously related to fat spoilage. Measurements of peroxide values, which are used to indicate the degree of rancidity or oxidation of fats, did not usually yield much information. On white fish there was very little formation of peroxides. The formation of free fatty acids, which are an indication of splitting of the fats and lipids, however, was readily correlated with the taste panel results. These methods for protein solubility and fat spoilage were used to check the taste panel grades in subsequent work.

Storage Life

The next part of the investigation dealt with the factors that affect storage life in various species of fish. These studies, conducted mainly on cod and haddock, showed that a freezing rate up to several hours was satisfactory. A freezing rate of 24 hours or so was not so favorable. But it was generally found that the storage temperature and time were the most important factors.

The results of storage of sharp frozen, commercially wrapped fillets of cod, sole, redfish, and Atlantic halibut are shown in the graphs (Fig. 1).

It will be seen that in all these species there is a period, especially at the low storage temperatures (—10°F.), where the frozen fish grades as good or better than fresh fish. For halibut this period lasts 3 or 4 months.

The influence of storage temperature is well shown. The deterioration is very much faster in all species at 10°F. than it is at 0°F. or at —10°F. The approximate storage life is shown in Table 1.

Halibut and rosefish may keep up to 18 months or more at -10°F., while plaice and cod deteriorate much faster.

From this, it appears that low storage temperatures of —10°F. or lower are necessary for long storage of frozen fish. Even then, the storage time is limited depending on the species. In this connection, it may be noted that in several European countries, storage temperatures of —30°F. are becoming common.

The protein solubility curves are almost parallel to the taste panel grades for cod and plaice. However, they show less correlation for halibut and almost no change occurs in redfish at —10°F. Free fatty acid development, Fig. 2, shows a good correlation with the storage life. Development is very rapid in cod, with a short storage life. Almost none is formed in redfish and little in halibut.

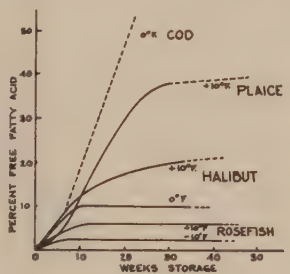

Fig. 2. Free fatty acid development, expressed as percent oleic acid in the extracted fat, in frozen fish of Fig. 1.

The general picture on the storage characteristics has been fairly well outlined. It would appear that further work on specific conditions and products could and should be done by the industry itself.

Other Factors

There are several other factors which enter into the picture. For instance, the effect of antoxidants such as ascorbic acid has been investigated. With plaice and with rosefish, the use of ascorbic acid had little effect on the oxidation of the fat. It had almost no effect on the development of off-odours and tastes. However, it was strikingly effective in preserving the red color of the rosefish and for this purpose it was most useful.

Another factor recently investigated is the effect of short periods of storage at temperatures above the normal storage, as would occur during refrigerator car shipment of fish. This investigation had to be postponed for several years because of lack of suitable facilities. To date, the results have shown that the effect on quality was much greater than was expected.

As many of you are aware, the temperature in the present refrigerator cars is often about 15° to 18°F., whereas most of the Atlantic coast storages run about —10°F. To measure the effect of storage at these temperatures for periods of a week or more, we obtained commercially frozen cod fillets and stored them at 0°F. After 1 month at 0°F., some of the cartons, which held 24 1-lb. boxes, were transferred to 15°F. and held at this temperature for 2 weeks. They were then replaced in the 0°F. storage. During this time quality assessments were made using both taste panel and protein extractability. The results are shown in Fig. 3. Almost immediately after the 15°F. treatment, the grade dropped sharply, curve B. After this drop, the grade then decreased at a similar rate to the control.

Other cartons were given the 2 week storage at 15°F. after 3 months storage at 0°F. Here again there was a similar drop in the taste panel score. The same occurred after 6 months and after 9 months storage at 0°F.

The net result was a shortening of the storage life by 2 to 2½ months. At the same time, while the fish did remain edible after the high temperature storage, the grade was very much reduced. Certainly, it is at least approaching the borderline for repeat order quality.

The effect on the quality of the fish reaching the market is the same

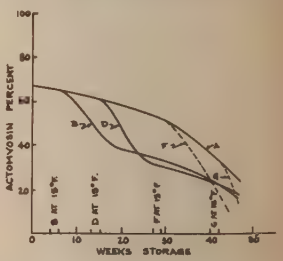

Fig. 3. Extractable actomyosin, as percent total protein, in stored frozen cod fillets.

A - stored continuously at 0°F.

B - stored at 0°F. for 1 month, then 2 weeks at 15°F., and subsequent storage at 0°F.

D - stored at 0°F. for 3 months, then 2 weeks at 15°F., and subsequent storage at 0°F.

F - stored at 0°F. for 6 months, then 2 weeks at 15°F., and subsequent storage at 0°F.

G - stored at 0°F. for 9 months, then 2 weeks at 15°F., and subsequent storage at 0°F.

whether it is held one month or for six months in producers' cold storages.

Further work has shown that placing the fish at 15°F. for shorter periods has a lesser but still significant effect. A 1 week period reduces the storage life by about 2 months and a 3 day period by about 1½ months.

No data are available on the time required for the fish to come down to —10°F. or whatever is the storage temperature in the inland wholesalers' warehouse. Poor unloading conditions could raise the temperature still higher, and if the cartons are placed in the cold store in a large pile, a long time will be required to reduce the temperature of the boxes on the inside of the pile.

Experiments are now being planned to determine a maximum allowable transportation temperature, but no results are available as yet.

In conclusion, lower temperatures should be used in transportation of frozen fish. Further, loading and unloading practices should be improved so that the frozen fish are not allowed to warm up as now appears to be the case. The quality of the fish reaching the consumer is determined by the cumulative sum of the handling conditions from the time the fish is caught until it reaches the consumer's plate.

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Stream ecology and production of anadromous fish

BEFORE we can predict the effect of man-made changes in the environment, we must have as clear an idea as possible of the *requirements* of anadromous fish in fresh water.

To an anadromous fish the freshwater environment is very restricted. Therefore, in seeking to exploit and conserve such fish, the question of stream *capacity* is paramount. It is not practical to describe a stream environment as being good or bad without taking into consideration the number of fish involved. Therefore, a search for ideal physical or other external conditions must be matched by a search for the right size of fish population.

The requirements of anadromous fish in fresh water are:

1) An adequate supply of oxygenated fresh water.
2) Protection against displacement and physical injury of eggs and young.
3) Suitable temperature.
4) Protection against predators and competitors.
5) Food (in many cases).

An obvious further requirement for anadromous fish is *access* from and to the sea. This is a special topic which is being discussed by others at this symposium and it will not be dealt with in this presentation.

All the above-mentioned requirements are, of course, met in some degree by natural trout and salmon streams. One or more of them, however, always puts a limit on the number of fish that can be produced and—from the standpoint of human desires—often a pretty low limit. If we are interested in obtaining maximum production of one or a few species of anadromous fish, we should not regard a natural "unspoiled" stream as an ideal environment. Such an environment, in fact, commonly kills off 60% to 99% of the potential salmon or trout before they can escape from it. Changing the condition of natural streams may make them either worse or better.

Referring to our list of "necessities", what is "an adequate supply of oxygenated fresh

water"? Or, to put the question in another form, what is the right number of fish for a given water supply? Figure 1 shows the number of seaward-migrating pink and chum salmon fry produced by various spawning populations of parent fish in Hooknose Creek, a small stream in the central area of the British Columbia Coast. Attention is drawn to two features of this graph:

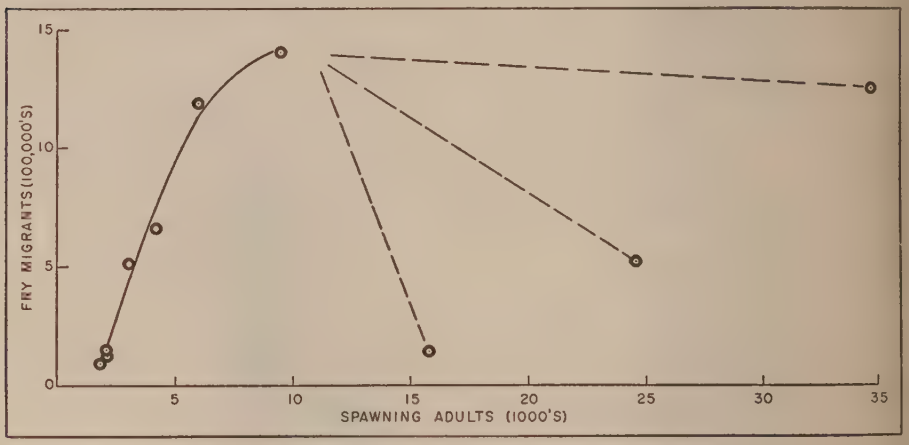

FIGURE 1.

OUTPUT OF PINK AND CHUM SALMON FRY FROM HOOKNOSE CREEK, B.C., IN RELATION TO NUMBER OF SPAWNING ADULTS.

(1) the steepness of the ascending limb indicates that, up to a certain density, an increase of spawners not only produces more fry migrants, but also produces them at a higher *rate;* (2) at densities above 10,000 or 12,000 spawners, production of fry may vary greatly, suggesting that annual variations in stream conditions have an important effect after the minimum or usual capacity has been filled.

When production follows the pattern shown by this graph, close regulation of the size of the spawning population is desirable. If the number of spawners is persistently kept at a much lower level than the indicated normal capacity of the streams, production may be reduced even more than proportionally. As conservationists we would say that the fish population is too small. Others with other water uses in mind, might say that there is too much water for the existing fish. It would not be altogether surprising to discover that many heavily exploited fish populations on this coast are—in this sense—supplied with too much water at the present time.

In some cases, the capacity of the stream may be determined by conditions prevailing at a particular season. Figure 2 shows a close correspondence between the catch of adult Cowichan River cohoes (per unit of effort), and the minimum summer flow of the river two years previously (i.e., the season which the young fish spent in fresh water). The inference is that during the years shown in the figure there were enough young fish to populate the river fully. The capacity of the river, however, varied in different years.

The effects of too little water (or too many fish) may be several.

One effect is the crowding of spawning fish onto less favourable ground, where drought, flood or frost may cut down the percent survival.

The various limiting factors are, of course, interrelated. The habit of burying eggs in gravel protects them from displacement, from *physical injury* and from *predators*. At the same time, it exposes them to other and very serious dangers. The underground water flow, on which the eggs and alevins depend, is very different in quantity (and often in oxygen content) from the

urface flow. Wickett (1955) believes that in order to provide generally favourable conditions or the development of salmon eggs, there should be an oxygen content of 7 parts per million, r more, and a stream flow through the gravel of at least 10 cm. per hour. Natural conditions requently fall below these specifications.

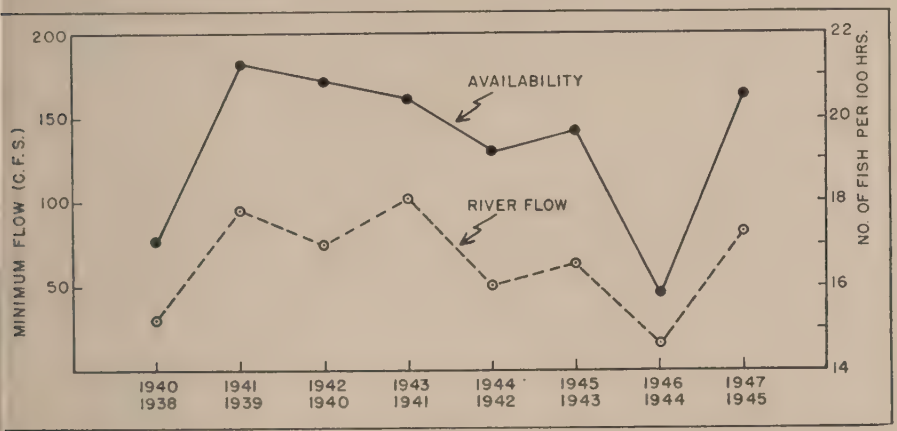

FIGURE 2.

VAILABILITY OF COHOES TO COWICHAN BAY ANGLERS (NUMBER OF FISH CAUGHT PER 100 OURS OF FISHING), COMPARED WITH MINIMUM SUMMER FLOW OF COWICHAN RIVER (CUBIC EET PER SECOND) TWO YEARS PREVIOUSLY.

Wickett has also shown that when water of initially suitable flow and content passes rough a large mass of eggs, those on the downstream side of the mass may not get enough xygen. At high spawning densities in Hooknose Creek roughly 10 tons of pink and chum lmon eggs are deposited in areas totalling not more than 10,000 square yards of bottom. is easy to conceive that with irregular concentrations of eggs in gravel of varying perme- bility, many eggs may get insufficient oxygen. In point of fact, under these conditions, heavy ortality before hatching is common.

Natural spawning grounds at best are compromises between *stability* and *permeability*,— they are stable enough to fulfil the function of protecting eggs from dislodgement by floods, ey may very easily become so compacted that they do not permit adequate flow. Under the isting conditions of salmon production (that is, natural reproduction without human "im- ovement" of the environment) gravel can be regarded as a necessary evil.

Temperature can be important and can be changed by human activities.

Brett (1952) has shown that young Pacific salmon in freshwater prefer temperatures of 2°C to 14°C and that temperatures of 24° or 25° are lethal. For Atlantic salmon lethal mperatures are somewhat higher. Some salmon streams (both Pacific and Atlantic) at nes reach or approach lethal temperatures. Changed conditions, resulting in an increase in mmer temperature, have probably reduced or eliminated certain runs.

Temperature changes do not necessarily affect all species occurring in a stream. For ample, pink and chum salmon will not be affected by summer conditions, since they are ot present in fresh water at this season. Very often temperature effects are *indirect*. High tem- rature may increase the danger of asphyxiation when adults or young fish are confined small volumes of water. Also it may favour an increase of *competitors*. In Japan, two species anadromous fish, *Salvelinus pluvius* and *Oncorhynchus masou* often occupy the same eams, the former species inhabiting upstream areas, while *O masou* is found in the lower aches. The two species make contact where the summer temperatures are about 13° to 15°.

In streams where only one of these species is present, its range, in terms of temperature is extended. (Miyadi 1956).

Where competitive relationships of this kind occur, temperature changes might evidently have striking effects on the distribution and abundance of the species concerned.

Survival from *predators* and *competitors* depends in part on conditions already mentioned—e.g. burying of eggs; favourable temperature. *Cover* may be a very important factor in the survival of young anadromous fish. There is, however, another kind of protection which brings us back to our initial theme of the importance of having the right number of fish. In some very important species of anadromous fish, e.g. pink and chum salmon, the fry go to sea as soon as they emerge from the gravel and are only present as free-swimming members of the stream community during the brief period of their seaward migration. They form a plentiful food supply for other fish for a few weeks in spring, but are not available at other times and therefore no long-term balance is set up between number of predators and number of prey. The predators can only consume a more or less fixed number of fry. If the fry run is small they may get 80%. If the run is large, perhaps only 20%. There is, therefore, an enormous additional advantage in a heavy emergence. This helps to explain how the output of fry can increase so rapidly in relation to an increase in the number of spawning fish (first part of the curve, fig. 1).

In general, the British Columbia streams which are inhabited by sea-going trout and salmon are not highly productive of fish *food*. The question of capacity is sometimes decided by this factor.

We might compare three common species of anadromous fish,—the steelhead; the coho; the chum. All occur in many of the same coastal streams; all reach much the same size at maturity. Recent estimates (necessarily rough) of total British Columbia stocks are: steelhead 500,000; coho, 5,000,000; chum, 12,700,000; i.e. a ration of about 1:10:25. No doubt various factors combine to determine these notably different populations. Particular significance, however, can be attributed to the fact that the young steelhead commonly spends 2 full years feeding in fresh water; the British Columbia coho spends one year; the chum does not feed, or feeds very little, in fresh water. These figures illustrate the restrictive effects of the freshwater environment and remind us that "capacity" can be very different for species with different life histories. Actually, the chum is less able than the other species to reach and occupy the upstream portions of watersheds. Stream capacity for chum salmon is limited by the extent of favourable spawning grounds situated within the rather limited powers of the species to migrate upstream. Coho and steelhead capacity is limited by food supplies. Spawning grounds do not represent the only (or necessarily the best) areas for young feeding fish and the latter tend to distribute themselves throughout a stream system, occupying and defending territories which are presumably large enough to support them. Even with the full utilization of available territory, however, it seems that British Columbia streams do not usually produce more than 20 sea-going coho smolts per 100 square yards of accessible stream area (Wickett, 1956). The output of pink and chum salmon fry in the same streams may reach 5,000 per 100 square yards.

This brief review of the requirements of anadromous fish in fresh water may provide some sort of background for estimating the effects which are likely to be produced by the changes which occur when streams become involved in power projects.

Diversions and water storage reservoirs always entail some changes in the volume or pattern of stream flow. Stream flow can be changed in various ways.

A reduction of the average flow, while maintaining or producing wide variations in water volume, will generally merely reduce the capacity of the watercourse,—both for the species which are limited by spawning area and species which are limited by feeding area.

When average flow is reduced, but at the same time becomes more stable, there may be a

reduction in the areas accessible for spawning purposes. On the other hand, losses of eggs and alevins from flood and drought may be reduced and, if minimum flows are not lowered, the capacity of the stream for feeding fish may not be greatly impaired.

In the case of Jones Creek, a very low flow has been stabilized and directed over a prepared spawning bed. By concentrating spawning fish, or introduced eggs, in this artificial channel, it has been possible to turn out as many pink salmon fry as were probably produced under the original stream conditions. Of course, the former feeding capacity of the stream for cohoes, etc., has not been maintained.

Some possible effects of water *impoundment* can be mentioned. Remarks are limited to consideration of the conditions *below* dams.

As already intimated, if impoundments are used to stabilize stream flow, they may prevent losses which are associated with flood or drought. Impoundments also act as settling basins for removing silt,—which can be a source of great mortality to developing eggs. Temperature effects are not always bad. If water is merely impounded and allowed to spill, the river temperature may be raised undesirably. However, water drawn from low down in a deep impoundment may tend to keep summer temperatures cool and favourable.

Moffett (1949) reported that during the first four years following construction of the Shasta Dam, the effects had been (1) a reduction in water temperature during summer, and an increase in water temperature in winter (2) a reduction of the seasonal variation in flow (3) the removal of much silt from the water. He says "The changed ecological complex in Sacramento River has had the following beneficial effects on salmon and trout production: (1) Water temperatures are at or near the optimum range; (2) higher river temperatures during late fall and early winter have accelerated development of salmon eggs and fry and increased the production of fish food; (3) more efficient production of young salmon has been made possible by the control of major floods; (4) the danger of silting has been emeliorated; (5) reduction of predator and competitor fish species has followed the lowering of river temperatures; (6) the survival and possible increase of spring-run salmon has been insured by the water temperature regime . . . .; (7) with the exception of volume of flow, operation of Shasta Reservoir has created headwater conditions in Shasta River for at least fifty miles downstream from Shasta Dam". Evidently in these years conditions below the dam were notably improved.

Moffett found reason to believe that conditions would not always be so favourable in the future, much more variation in flow being foreseen. In the years since he wrote, the Sacramento runs of chinook salmon appear to have held generally at a high level (the 1956 population showed a marked drop, but only time will show whether this is a temporary condition or otherwise). However, my main point in referring to the Shasta Dam is to illustrate the fact that highly beneficial types of water control are possible,—not that such installations are usually operated in the best interests of fisheries.

In conclusion, I believe the following points are worth emphasizing, although they may well seem obvious:

A natural stream is a complex organization. It is not a specialized farm for the intensive production of one or a few species of salmon and trout. From the point of view of maximum production of these species, natural streams can be changed radically,—either for better or for worse.

Various logical measures have been taken to maintain the stream production of anadromous fish when this has been impaired or threatened by power projects. In some cases, similar measures might be even more productive if applied to streams which are still "natural". Let us not always confine ourselves to salvage jobs.

A good stream is only good when it has the right number of fish in it. Accessibility, optimum temperature, good spawning grounds and food supplies,—these will not ensure good

production unless they are matched by the right size of spawning population.

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DISCUSSION

DR. LARKIN: Would you explain further your statement that there may be other considerations besides volume of flow or expressing numbers of fish per unit of area in deciding on carrying capacity of streams.

DR. NEAVE: Shortage of various supplies can limit capacity. For example, surface food supplies might be less plentiful on a broad stream section than on an equal area in which the water is split up into smaller channels. Capacity could refer to limitations of spawning area or feeding area as well as to total volume of flow. I think capacity is a nice elastic term.

MR. HOURSTON: If you have had any example of where coho have adjusted to lake environment would you tell us about it?

DR. NEAVE: I would refer you either to the Chairman or Dr. Ricker to answer that question.

DR. RICKER: All I know about it is that we used to catch lake coho regularly in Cultus Lake when we were netting during 1932-38. They were taken more often than trout were, and they varied in number with the size of anadromous coho runs that had entered the lake to spawn above it. We caught them in largest numbers in the spring of their third year, but along into the summer and autumn they seemed to become scarce. A very few were taken which were mature: I don't know whether they spawned or not, but I don't know any reason why they shouldn't have. However, these lake-reared fish were not maintaining their own stock; each year's supply was mainly the progeny of the anadromous stock. Concerning coho going to sea at age 2+, that happened to some few at Cultus, anywhere from ten or twelve up to fifty or so occurred during a spring migration. Some which Dr. Foerster marked in 1927 came back predominantly in the same year.

MR. JOHNSON: Large diurnal fluctuations in water levels are a common feature in power development. Would you care to comment on any research or findings on effects of diurnal fluctuations in water flow with respect to the various species?

DR. NEAVE: I would say that stability is preferable. No doubt short term fluctuations sometimes help adults ascending a river system to get through areas otherwise difficult. Occasional floods of that kind can be beneficial as long as they are not so prolonged or severe as to affect the spawning areas or the fish food at the bottom.

DR. MILLER: I am not too familiar with the habits of these three fish, but those relations: 1-10-25 look like the natural food chain. Would that be the difference, the level of their basic food supply?

DR. NEAVE: The coho does feed on the chum to some extent, but only for a brief period in the spring of the year. During a good deal of the time the coho and steelhead are competitors—they eat a good deal of the same organisms in the streams.

DR. FOERSTER: Is it not likely that artificial means could increase natural production of coho and chum?

DR. NEAVE: I think dams can be excellent, but they shouldn't be power dams, they should be dams designed for fisheries purposes. Anything that would keep down large variations in flow would, I think, be beneficial. This apparently happens in some cases and for some periods with storage dams for power purposes. In general, power requirements don't tend to stabilize the flow.

DR. FOERSTER: Perhaps they should be made to stabilize the flow as a condition of the dam.